RECLAMATION CRITERIA FOR WELLSITES, BATTERIES AND ASSOCIATED FACILITIES

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RECLAMATION CRITERIA FOR WELLSITES AND ASSOCIATED FACILITIES – 2004 UPDATE TECHNICAL RATIONALE DOCUMENT

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TABLE OF CONTENTS

LIST OF FIGURES iv

LIST OF TABLES v

ACKNOWLEDGMENTS vi

1. INTRODUCTION 1

2. STAKEHOLDER COMMENTS 1
2.1 Landowners 4
2.1.1 General Comments 4
2.1.2 Landscape 4
2.1.3 Soils 4
2.1.4 Vegetation 4
2.1.5 Other 5
2.2 Industry 5
2.2.1 General Comments 5
2.2.2 Landscape 5
2.2.3 Soils 5
2.2.4 Vegetation 6
2.3 Consultants 6
2.3.1 General Comments 6
2.3.2 Soils 6
2.3.3 Vegetation 7
2.4 Regulators 7
2.4.1 General Comments 8
2.4.2 Landscape 8
2.4.3 Soils 8
2.4.4. Vegetation 8

3. RESPONSE TO OVERALL OBJECTIVES FOR THE PROJECT 9
3.1 Land Use Categories 9
3.2 Overall Site Assessment Scheme 10
3.3 Sampling Scheme 10
3.4 Soil Assessment Parameters 11
3.4.1 Topsoil Depth 11
3.4.2 Topsoil Quality 14
3.4.3 Admixing 14
3.4.3.1 Soil Organic Matter 15
3.4.3.2 Texture 19
3.4.3.3 Aggregate Size and Strength 21
3.4.4 Soil Profile Assessment 25

TABLE OF CONTENTS (continued)

	3.4.4.1 Cone Penetrometry	25
	3.4.4.2 Bulk Density	27
	3.4.5 Gravel and Rocks	30
3.5	The Use of Amendments to Improve Topsoil Quality	31
3.6	Landscape Parameters	35
3.7	The Use and Value of Management Plans	35
3.8	Alternative Assessment Techniques	36
4.	REQUIREMENTS IN OTHER JURISDICTIONS	37
4.1	Site and Soil Assessments	37
	4.1.1 Site Assessment Requirements	37
	4.1.2 Site Reclamation Requirements	39
4.2	Vegetation Assessments	42
5.	VEGETATION MEASUREMENT TECHNIQUES	47
5.1	Defining the Vegetation Attributes	47
5.2	Defining the Methods of Measurement	52
	5.2.1 Daubenmire	53
	5.2.2 Density	55
	5.2.3 Harvest	57
	5.2.4 Photo Monitoring	59
	5.2.4.1 Photoplots	59
	5.2.4.2 Photopoints	60
	5.2.4.3 Aerial Photography and Remote Sensing	61
	5.2.5 Statistical Considerations	62
6.	RANGE HEALTH ASSESSMENT	62
6.1	Indicators of Range Health	64
	6.1.1 Integrity and Ecological Status	64
	6.1.2 Community Structure	65
	6.1.3 Hydrologic Function and Nutrient Cycling	65
	6.1.4 Site Stability	66
	6.1.5 Noxious Weeds	66
6.2	Assessment Methodology	66
7.	SOIL AND VEGETATION VARIABILITY	67
8.	TRAINING	70
9.	PERFORMANCE MONITORING	71
9.1	Soil Performance	71
9.2	Vegetation Performance	72
9.3	Effectiveness of Pre-Construction Site Assessments	72

TABLE OF CONTENTS (concluded)

10. REFERENCES CITED 74

APPENDIX 1: STAKEHOLDER CONTRIBUTORS 82

LIST OF FIGURES

		Page
1.	Crop yield reduction (%) relative to soil loss (cm)	13
2.	The difference between foliar cover (on the left) and canopy cover (on the right)	50
3.	The Daubenmire six cover class frame	54
4.	Nested plots used to measure density	56

105-01766/

LIST OF TABLES

Page

1. Vegetation requirements to be met within 18 months of reclamation 44
2. Daubenmire cover classes used in estimating vegetation cover 55
3. Important rangeland functions 63
4. The values and benefits of healthy range to various rangeland users 64

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1. INTRODUCTION

This document provides the scientific rationale and explanation of why each criteria parameter is being recommended and the basis for the criteria associated with each. Feedback from stakeholders indicated that overall, the Reclamation Criteria for Wellsites and Associated Facilities – 1995 Update (Alberta Environmental Protection 1995) were relatively good. Several stakeholders indicated that on a scale of one to five the criteria ranked about a four. The general feeling was that the 1995 criteria really improved reclamation practices in the industry. Clearly, each group of stakeholders had some specific concerns. For example, landowners were generally concerned that the soil replacement depths were not adequate. This directs one to the literature pertinent to topsoil depths or the effect of "losses" of topsoil on soil capability and crop productivity. All stakeholders had some comment regarding "admixing" and its effect on soil capability and productivity. Related literature pertinent to the effect of textural change (increased clay content) and change in organic matter (total organic carbon) content of replaced topsoil more technically define the effects of admixing.

This document provides a response to the topics outlined in the original request for proposal for the project. A literature review for each of the relevant topic areas is provided. A list of the references cited in the review and a list of all references reviewed are provided. The rationale for the revisions was based on the prime consideration of how any of the changes proposed would advance or improve the quality of the reclamation done.

It should also be noted that there will always be exceptions to what is defined and no written criteria can account for all of these.

2. STAKEHOLDER COMMENTS

The stakeholders were contacted from a list of names provided by Alberta Environment. This list included the names of individuals invited to participate in regulatory update meetings. As individuals on the list were contacted the list grew in size based on the additional contacts recommended by those contacted and individuals who voluntarily responded after hearing about the project. In several instances the industry (oil company) staff recommended consultants that could provide input. A list of stakeholders that provided feedback is provided in Appendix 1.

The "interviews" were conducted primarily by phone. The process was relatively informal and included the following steps:

- stakeholder was asked to provide general comments regarding criteria and then provide specific areas of concern or areas that currently work well from their perspective;
- interviewer asked questions pertinent to topics that may not have been touched on by the stakeholder. The topics included the three main components of the criteria, i.e. landscape, soils, and vegetation;
- interviewer asked questions pertinent to the terms of reference and overall objectives of the project:
  - review the current criteria document and all associated Information Letters
  - review the land use categories and advise on any improvements/changes including the potential use of soil Orders in combination with land use categories
  - review the overall site assessment scheme
  - review the grid sampling scheme and suggest improvements
  - review the soil assessment parameters and suggest more objective and clear assessment protocols in relation to topsoil depth, topsoil quality, admixing, texture, soil profile assessment, rocks and gravel
  - review the use of amendments (straw, manure, other) to improve topsoil
  - review the use and value of management plans
  - review data reporting
  - ensure that the new criteria have a realistic basis relative to current science and are consistent with the legislated goal of equivalent capability.

A project to identify improved methods of evaluating revegetation for determining reclamation success on cultivated land was initiated in September, 2002 prior to the review of the overall criteria. As part of this project seven field staff representing the regional offices of Alberta Environment and five industry staff (four consultants and one major oil company representative) were interviewed. The following is a set of questions that was used as a basis for the discussions.

1) Can you briefly describe what you do relative to vegetation when you are conducting an inspection/assessment at a given site?
   - density
   - height
   - head size
   - rooting

   Methods used?

2) In your region what crops do you generally deal with?
   - grains
   - forages
   - oilseeds (canola)
   - other

   What measurements do you conduct on canola? Are there some crops that are more problematic than others?

3) What is the time window for doing assessments in your region? When would you prefer to do the assessment or "when" is the best time to be conducting the assessment in terms of stage of crop development?

4) What are your concerns or what do you see as a limitation with the present system?

5) What tools could you use to do a better job?

6) Are there issues or concerns that may be unique to your region compared to other regions in the province?

The work completed on this specific project is incorporated into the overall review package. A summary of the responses received relative to updating the 1995 criteria document is provided below.

2.1 LANDOWNERS

Eight landowners were interviewed and additional input was received at a meeting with the Surface Rights Federation held March 12, 2003 in Camrose. The landowners raised several issues that fell within the purview of the criteria update and several that did not.

2.1.1 General Comments

- criteria system needs to be simple but robust
- criteria are ambiguous
- pre-construction site assessments should be done – planning critical to reclamation success
- more training needed for equipment operators
- many farmers not aware that criteria exist
- landowner recommendations regarding practices that could improve soil salvage operations are being ignored

2.1.2 Landscape

- no concerns expressed

2.1.3 Soils

- topsoil conservation and the 80%, 70%, and 60% soil replacement depths – what is the target "80% of control" based on – is it natural variability?
- admixing issues. Soil salvage in areas with shallow topsoils and Luvisolic soils; poor salvage practices in general
- would like greater use of amendments such as manure
- issues associated with "importing" of topsoil. Too much topsoil is being moved to compensate for poor salvage and replacement practices
- soil compaction, particularly in upper subsoil
- issues surrounding zero tillage

2.1.4 Vegetation

- yield assessments would be ideal for cultivated crops
- head length, number of kernel measurements should be done
- concerned about crop "quality" as well as productivity. An example is whether barley on a wellsite will meet "malting" criteria in comparison with the crop adjacent to the wellsite
- native range recovery. Re-establishment of fescue grasslands
- invasive plants are a concern in the native grasslands
- weed control is a concern

2.1.5 Other

- concerns regarding enforcement of regulations
- contamination
- every audit should include an inquiry
- construction practices could be improved through use of more suitable equipment
- impact of wellsites on land sales
- no criteria in place for sites that are not producing and not being reclaimed
- implications for "organic" farming

2.2 INDUSTRY

Three industry staff were interviewed. Several of the other industry staff contacted provided a referral to consultants working on their behalf.

2.2.1 General Comments

- minimum disturbance approaches should be used where feasible
- mixed response regarding value of pre-construction site assessments
- current criteria are easy to use and doing the job
- don't want criteria that are too "prescriptive"
- "interpretation" of the criteria rather than criteria themselves is more of a concern
- need to appreciate limitations due to size of equipment, time of year of construction etc.

2.2.2 Landscape

- no major concerns/comments

2.2.3 Soils

- too many grids
- lack of understanding that controls may not represent the wellsite
- replacing topsoil is not the only way to achieve equivalent capability
- "admixing" is a good idea in principle but viewed differently than was intended. Not necessarily a symptom of a problem
- current soil replacement depth criteria are reasonable
- change needed in the way texture is used in the criteria
- soil sampling could provide benefit if done properly but does increase costs and extends time interval to complete assessment and reporting

2.2.4 Vegetation

- vegetation is an indicator
- yield measurements are not practical
- techniques are needed to assess crop growth at various stages
- visual assessment of vegetation performance is preferred approach
- difficult to compare wellsite and offsite vegetation in the native grassland areas
- longer time frame needed to determine revegetation success in these areas

2.3 CONSULTANTS

Seventeen consultants were interviewed. Some of the individuals interviewed were providing input for groups of up to 10 individuals.

2.3.1 General Comments

- overall feeling is that the 95 criteria document is pretty good and that it really improved reclamation practices in the industry
- criteria need "tweaking" rather than "revisions"
- criteria should not imply that soils and crops are going to be the same on site as offsite
- criteria serve "meeting intent of equivalent capability"
- general feeling that pre-construction site assessments are beneficial but question is how you use them in the reclamation process. Most useful at "unique" locations
- more training is needed
- concern re level of consistency of application/interpretation of criteria between reclamation inspectors in the different regions

2.3.2 Soils

- mixed reaction regarding grid system. Some are happy with current system. Some would rather have less grids but better descriptions
- observation point in the grid needs to be representative of the grid, not necessarily the centre point of the grid
- some would like to see less emphasis on topsoil depth however most feel current replacement depth criteria are fine
- "admixing" is difficult to measure, easier to look at consequences such as texture, organic matter and aggregate characteristics
- some feel that more emphasis should be placed on texture than organic matter content – how much difference in carbon has a measurable effect on the crop?
- most do not like the current texture class criteria approach and would rather see a system that allows for a certain amount of change in clay content

- most support the idea of sampling and analytical work but mainly when there is a dispute to resolve
- many would like to see a better definition for topsoil and the role of the Ae horizon
- there is general support for the use of amendments such as manure provided that appropriate application rates are used
- number of controls and selection thereof is problematic. General agreement that more than four controls are needed

2.3.3 Vegetation

- wide range of opinions regarding vegetation assessments. Some indicated they were not in favor of a "standardized" or defined approach. Many felt that some better defined techniques are required
- some would like to have criteria that would allow for assessment at different stages of crop development
- some suggested a "phased" approach whereby an initial "simple" assessment is done at all sites and more detailed one completed if problems arise
- some indicated they would not do a "sign-off" without a crop present
- timing of assessments is a major issue in terms of getting them done in the context of operating a company and maintaining realistic staffing levels
- vegetative assessments are time consuming and should only be done where differences are obvious
- individuals who are doing measurements of plant density, plant height, head length are likely not doing enough replication
- reducing cover density requirements to increase diversity in native rangeland areas generally viewed as a good idea but raises some caution regarding erosion, especially wind erosion
- measurement techniques are needed for the different crops
- assessment of weeds needs to be dealt with
- some indicated that "biomass" measurements would be a good tool for forage crops

2.4 REGULATORS

Fifteen regulatory staff from Alberta and one each from British Columbia and Saskatchewan provided input. The latter provided input on the status of reclamation criteria in their respective provinces. The comments below are based on feedback received from the Alberta staff.

2.4.1 General Comments

- 95 criteria resulted in better reclamation practices than prior to their use
- the goal of reclamation is to achieve equivalent capability
- minimum disturbance approaches should be used where feasible
- equipment and techniques developed over the years provide an opportunity to improve practices and do a better job of construction and reclamation
- support concept of pre-construction site assessments. Protocols re how they are conducted and used are needed
- a few recommended other assessment approaches that might be considered

2.4.2 Landscape

- no major concerns/comments
- a few commented on implications of minimum till and no till farming practices

2.4.3 Soils

- mixed comments regarding number of grids. Some feel current approach is good, others would like to reduce number of grids. A few questioned the usefulness of the distribution and quality tolerances
- some feel that definition of "topsoil" needs to be improved
- most are dissatisfied with the 60%, 70%, 80% soil replacement criteria
- four controls are not adequate – need more. Also problems associated with selection of representative controls
- generally favor soil sampling and analytical approach
- all commented on the "admixing" topic and concerns regarding "dilution" of topsoil. Some would like to see admixing as a "factor" rather than just a "flag" Overall area of soil parameters – texture, organic matter, aggregates needs to be strengthened.
- some would like to see more emphasis on the total root zone rather than just the topsoil layer

2.4.4 Vegetation

- minimal measurements done when visual assessment indicates that 80% criteria has been met
- would like to see some "formalized techniques" or "defined methods" as there is no specific set of procedures used currently. Some definition of methods would result in better quality assessments and reporting. Would like to see "alternate" techniques defined as well
- generally don't agree with assessments being conducted at flag leaf or post flag leaf stage
- some insist on mature crop for conducting vegetation assessment
- most feel that stubble assessments can be used, especially in situations where major differences rather than subtle differences are evident

- several questioned whether assessments are necessary for each grid
- several would like to have yield assessments completed
- several would like to have two to three consecutive years of vegetation data
- several commented on reduction of cover density to promote invasion and diversity in the native grasslands
- natural recovery is being promoted for grasslands and green zone
- more emphasis on reforestation in green zone
- more consideration for wildlife needs in portions of green zone
- more use of native grasses and legumes
- problems with weeds

3. RESPONSE TO OVERALL OBJECTIVES FOR THE PROJECT

Each of the topics outlined in the project deliverables for the review are addressed in the context of providing a rationale for the factors and associated criteria based on a review of the available literature. The Reclamation Criteria for Wellsites and Associated Facilities – 1995 Update document (Alberta Environmental Protection 1995) and all Information Letters were reviewed. The Information Letter materials were incorporated into the relevant sections of the criteria document.

3.1 LAND USE CATEGORIES

The land use categories remain similar to those defined in the Reclamation Criteria for Wellsites and Associated Facilities – 1995 Update (Alberta Environmental Protection 1995). During the interview process a number of individuals raised concerns related to wellsite construction in areas of Solonetzic, Luvisolic and Brown Chernozemic soils in particular. Although several individuals indicated it might be helpful to develop criteria based on the different regions or soil zones they didn't have a sense of how this could be accomplished in a practical manner. One of the major limitations of this approach is the establishment of the "boundaries" between the different zones and the "transition" areas on either side of the boundaries. Following in depth consideration of a variety of approaches it became apparent that the advantages of this approach would be outweighed by the disadvantages.

3.2 OVERALL SITE ASSESSMENT SCHEME (PASS/FAIL OR CAPABILITY, JUSTIFICATION, STEP-OUTS, DEFAULTS OF WHITE AREA FOREST TO GREEN)

The overall site assessment scheme was reviewed with substantial feedback received from interviewees. Many were satisfied with the assessment scheme as currently defined while others made recommendations for change. Several suggested having a similar approach for all land uses.

3.3 SAMPLING SCHEME

The review of the sampling scheme considered the grid approach including number of grids and whether the soil and vegetation grids should be the same. In addition the paired approach and related sampling on access roads as well as the number of controls was evaluated.

Most were satisfied with the number of grids used at the sites. Some would have liked to see a smaller number of grids whereas a few indicated they would like to see a larger number of grids. A few individuals proposed alternative approaches to the current square grid system including an approach that has a lesser amount of samples being taken in the outer perimeter of the lease as in the inner portion. This proposed approach was based on the premise that the larger the lease size, the lesser the likelihood of disturbance in the outer portion. The current required number of four controls was considered inadequate by the majority of individuals. Some indicated that they might use as many as 20 controls in some instances. Defining the absolute number of controls required was a difficult task. The number of controls evaluated is based on the variability of the field in which the disturbance is located and to some extent the experience of the personnel conducting the assessment. It is obvious that if one is located in a relatively level area of Chernozemic Black Soils with a relatively thick Ap or Ah horizon one would require less controls than in a field of Solonetzic soils or Luvisolic soils across a rolling landscape. This is an example of the "judgment" approach that works well for experienced personnel. A total of eight controls is recommended recognizing that in some cases this may exceed the number needed while in others it may not be adequate. Current criteria for assessing access roads were deemed satisfactory.

3.4 SOIL ASSESSMENT PARAMETERS

3.4.1 Topsoil Depth – is percentage adequate or what should be used, are depth variability allowances reasonable, are minimum topsoil depth numbers below which depth targets don't exist reasonable and fair – suggest improvements.

The percentages currently in use prompted significant discussion. Landowners and regulatory staff felt the percentages are too low and do not reflect adequate soil conservation practice. On the other hand, some consultants and industry staff feel that too much emphasis is being placed on topsoil depth and that replacing topsoil is not the only way to achieve equivalent capability. The percentages defined in the Reclamation Criteria for Wellsites and Associated Facilities – 1995 Update (Alberta Environmental Protection 1995) are retained, however the requirements for sites constructed subsequent to August 31, 2003 will require the replacement of 90% of the "topsoil" layer. The increase is based on the overall goal of soil conservation and achieving equivalent capability of the site. Furthermore, advances in equipment design, equipment availability and some of the tools available support the argument that soil handling techniques including both the salvage and replacement components can be improved upon.

Power et al. (1981) stated that topsoil thickness is an important parameter in determining soil quality and productivity. He went on to say that with topsoil loss subtle changes occur in soil properties that reduce crop productivity and create soil management problems. Once this topsoil has been lost, the remaining soil will have to be treated to restore its full productivity.

An extensive review of the literature was conducted to assess the impact of topsoil depth on soil quality and the relationship to soil productivity and soil capability. With the exception of a project undertaken in 1988 to identify the relationships between subsoil compaction, topsoil depth, and barley productivity under a range of conditions (Thacker 1990), there were no reference studies found that were specifically established to assess topsoil replacement depths in this reclamation context. The final results for this study were not located.

Most of the studies conducted that have some relationship to soil depth were associated with evaluating soil erosion effects on soil quality or evaluating opportunities to restore productivity to eroded soils via the use of fertilizers.

The studies conducted to assess the effect of topsoil loss due to erosion on crop productivity involved:

- comparing yields from eroded and non-eroded fields;
- comparing yields from artificially eroded (scalped) and control soils;
- estimation of the incremental effects of topsoil added back to severely eroded soils.

Larney et al. (1995) established sites on Dark Brown Chernozemic (Lethbridge), Brown Chernozemic (Taber), and thin Black Chernozemic (Hill Spring) soils by removing 0 cm, 10 cm, and 20 cm of topsoil. Removing 10 cm of topsoil resulted in a reduction of spring wheat yield of 43 to 66 % under non-fertilized production. Removal of 20 cm of topsoil resulted in a yield reduction of 60 to 89%.

Smith and Shaykewich (1990) reported yield loss proportions due to soil erosion based on a study involving scalping increments of 0, 5, 10, and 20 cm of topsoil from six soils in Manitoba. The yield losses ranged from 4 % to 15 % for the 5 cm soil removal, 9 % to 29 % for the 10 cm removal, and 17 % to 59 % for the 20 cm removal.

Tanaka and Aase (1989) mechanically removed soil depths of 0, 6, 12, and 18 cm of soil from a Typic Argiboroll (Dark Brown Chernozem) in Montana. Yield reductions of spring wheat were 7%, 39%, and 44% compared to control for the 6 cm, 12 cm, and 18 cm soil removal scenarios and no fertilizer added treatments.

Tanaka (1990) reporting on additional aspects of the study described above indicated that topsoil removal significantly reduced the capacity of spring wheat plants to convert water and radiant energy to grain and dry matter. He went on to state that "the most environmentally acceptable approach to sustaining agricultural production and crop quality in the northern Great Plains is to keep soil erosion at or below tolerable limits."

Figure 1 provides a comparison of crop (spring wheat) yield reduction with soil loss for Larney et al. (1995), Smith and Shaykewich (1990), and Tanaka and Aase (1990). The 5 cm soil loss resulted in reduced yields of 4 to 15% while the 10 cm and 20 cm soil losses resulted in yield reductions of 20 to 66% and 40 to 89% respectively.

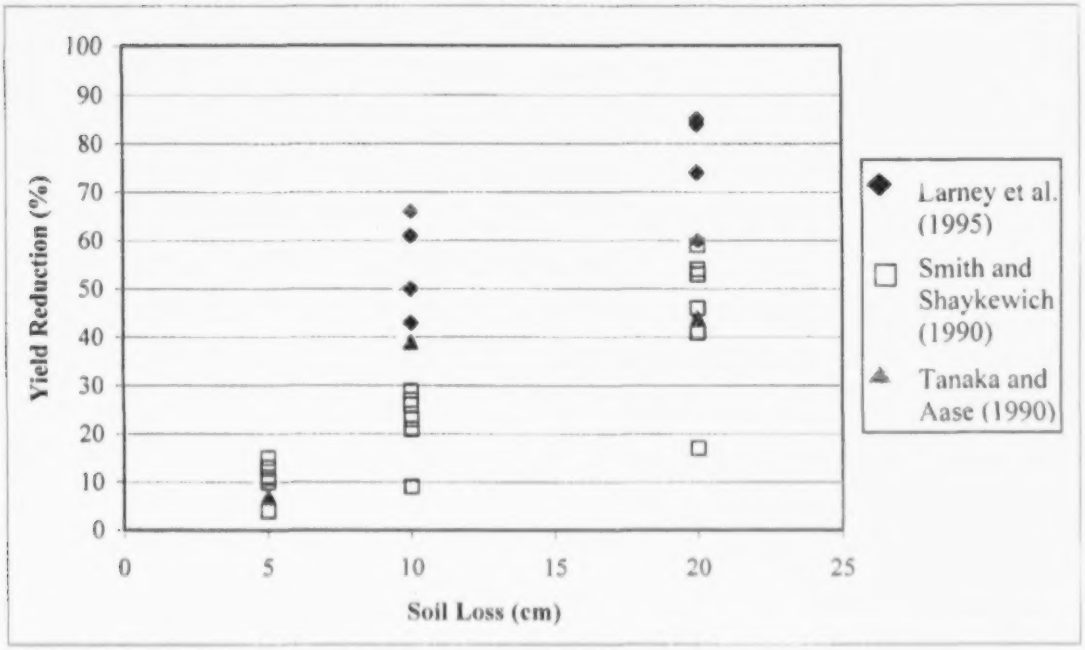

Figure 1. Crop yield reduction (%) relative to soil loss (cm).

Verity and Anderson (1990) evaluated the impact of varying degrees of erosion on productivity by adding back incremental depths of 0, 5, 10, and 15 cm of topsoil to eroded sites. They concluded that grain yields were increased by 45 to 58% by adding 5 cm of topsoil, with additional topsoil (10 or 15 cm) generally increasing yields slightly, but at a decreasing rate.

Mielke and Schepers (1986) added topsoil thickness of 0, 10, and 20 cm to an exposed C horizon of loess soil in Nebraska. They found that corn yields increased up to 29% as a result of the topsoil addition.

Several other studies including one conducted by Olson (1977) in the western Corn Belt demonstrated the effect of topsoil loss on corn yields. These studies involved relatively large increments of topsoil removal (0, 30, and 45 cm) that are rather significant compared to the indigenous topsoil thicknesses for many of the soils in Alberta.

In summary, topsoil loss has a significant bearing on soil quality, capability, and productivity. Conserving topsoil is a critical component of wellsite construction and reclamation.

3.4.2 Topsoil Quality – how best to assess quality; e.g. by organic matter, color.

Topsoil quality is based on a number of parameters. The parameters assessed should include texture, organic matter, and aggregate characteristics. Color can be used as an indicator of soil quality especially as it relates to the mixing of soil horizons or the incorporation of subsoil or B horizon material into the topsoil layer. It should be noted that several stakeholders recommended the use of currently accepted protocols for describing soil attributes. As a result, the soil attributes are described or defined relative to the criteria of the Canadian System of Soil Classification (Agriculture and Agri-Food Canada 1998) and The Manual for Describing Soils in the Field (Expert Committee on Soil Survey 1982).

Soil quality and health are difficult to define, considering the integration of the physical, chemical, and biological soil attributes that define soil function (Doran and Parkin 1994). Doran and Parkin (1994) define soil quality as "the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health," while Larson and Pierce (1994) provide a simple, operational definition: "fitness for use". Fauci and Dick (1994) state that "crop rotations, residue management, fertilization, cultural, and other management practices can significantly affect soil quality by changing soil physical, chemical, and biological parameters."

Janzen et al. (1995) identified several soil attributes that could serve as definitive quality criteria for soils in the semi-arid regions of western Canada including organic C and N concentration, light fraction C and N concentration, mineralizable C and N concentration, and microbial C concentration.

The United States Department of Agriculture (1998) concludes their paper by stating that "Poor soil quality is reflected in decreases in organic matter, aggregate stability, phosphorus levels, and potential plant-available water. The net result is a decrease in soil productivity."

3.4.3 Should admixing be a parameter and if not, what should be used to determine degradation due to mixing of soil horizons?

The concept of admixing raised more discussion than any of the other topics addressed. The primary concern related to assessing the extent of mixing using the current subjective approach. From the regulatory staff perspective most individuals wished to retain it as a "flag" in the criteria while others wanted to see it used as a parameter. On the other hand the

consultants and industry staff wished to evaluate the consequences of admixing rather than trying to measure the extent of its occurrence. In other words, one should be looking at other soil parameters such as texture, organic matter content, color, etc. The approach adopted in the revised criteria is one of assessing texture, organic matter (total organic carbon content) and aggregate size and strength.

3.4.3.1 Soil Organic Matter

Paustian et al. (1997) stated, "farmers have long recognized the organic matter content of a soil as a key attribute of soil fertility. It seems likely that this awareness, at least in the intuitive sense of recognizing dark-colored, friable, and earthy smelling soils as favorable sites for growing crops dates back to the beginning of agriculture."

Smith (1998) indicated crop yield to be an important indicator of soil quality, and that soil organic carbon (organic matter) is commonly used as a gross universal indicator of soil quality. Fauci and Dick (1994) stated that soil organic matter, measured as total C, is one of the properties most widely used to describe soil quality.

McGill and Bailey (1999) stated the importance of soil organic matter: "1) it is a vital component of the soil fabric, improving soil structure, soil tilth, soil fertility, and soil health, which is essential for sustainable agricultural productivity; and 2) it is a sink for atmospheric C thereby reducing the emission of the greenhouse gas CO_2." They define soil organic matter as: "1) partially decayed plant materials that are no longer recognizable as plant remains; 2) the soil microflora and micro- and meso-fauna (soil microbial biomass); together with, 3) the products of decomposition, including humic substances and organic constituents both of which may be present as organo-mineral complexes. Most quantitative data in the literature are for soil organic C (SOC), and C is a major constituent of SOM. Consequently, SOC may be used as a surrogate for SOM."

McGill and Bailey (1999) outlined the contributions of SOM to biological, chemical, and physical attributes of soils. The contribution to biological attributes includes:

- energy supply
- habitat for organisms
- nutrients
- overall increase in element cycling, biological activity, and biodiversity

The contribution to chemical attributes includes:

- retention of ions
- sorption of xenobiotics
- sink for atmospheric C
- buffer for pH and ion concentrations
- reduction in toxicities

The contribution to physical attributes includes:

- improved tilth, reduced draft during tillage
- aggregation and resistance to erosion
- water relations including infiltration and retention
- pore size distribution
- temperature relations including reflectance and thermal conductivity

Carter (1996) stated "soil organic matter is a fundamental but transient component of the soil that controls many chemical, physical, and biological properties affecting the ability of a soil to produce food, fibre, or fuel. It is the primary source of energy for the soil ecosystem, and a major source of and a temporary sink for plant nutrients in agroecosystems." Gregorich et al. (1995) indicated that soil organic matter is important in maintaining soil tilth, aiding the diffusion of air, the retention and infiltration of water, reducing soil erosion, and controlling the efficacy and fate of applied pesticides.

Loveland et al. (2001) noted that there is a widespread perception that the amount of SOM or SOC in soils needs to be kept above a minimum level in order to prevent, or at least minimize, irreversible decline in a range of soil properties. Greenland et al. (1975) proposed a "rule of thumb" that soils in England and Wales should be regarded as structurally unstable if the SOC content fell below 2% which is the equivalent of 3.4% SOM. In an attempt to evaluate the quantitative evidence for critical levels of SOM in relation to specific soil properties Loveland et al. (2001) examined 1500 papers relevant to temperate agriculture and soil types in the UK. The majority of the papers deemed to contain "hard" evidence or good science were related to aggregate stability. They noted that one study in particular provided the most comprehensive investigation of the relationship between total SOM and aggregate stability through examining 519 samples of topsoils and subsoils from the western USA and Canada. They found that aggregate stability declined increasingly sharply as SOM contents fell below 4%. Loveland et al.

(2001) concluded from their review that it would be inappropriate to set thresholds for critical levels of SOM or SOC for particular soils.

Reinl (1984) and McGill et al. (1988) reported that cultivation dilutes the concentration of SOC in surface soils by mixing organic matter rich A horizons with the underlying B horizon. They recommended that in light of the large proportion of SOC that is in the Ap horizon, land management practices that avoid further exposure or dilution of SOC should be strongly encouraged. The same phenomenon of dilution occurs when surface soils or topsoils are salvaged in preparation for construction of a wellsite.

Carbon and nitrogen are so intimately associated with one another that practices that promote the maintenance of soil carbon levels will also promote the overall nitrogen retention and increase the overall nitrogen supplying power of the soil (McGill and Bailey 1999).

Soil organic matter is the primary source of nitrogen (Albrecht 1938). In the latter stages of decay of most kinds of organic matter, nitrogen is released as ammonia and subsequently converted into soluble or nitrate form. The level of crop production is often dependent on the capacity of the soil to produce and accumulate this form of readily usable nitrogen.

Izaurralde et al. (1998) conducted a study to determine the immediate effects of topsoil removal on crop productivity loss and its restoration with commercial fertilizers. The two experimental sites included a Black Chernozem with an Ap of 30 cm in thickness near Josephburg, Alberta and a Gray Luvisol with an Ap of 15 cm near Cooking Lake, Alberta. Topsoil removal included depths of 0, 10, and 20 cm. The organic carbon levels in the 0 to 10 cm depth of the Black Chernozem were 40.2, 34.3, and 25.0 g kg^{-1} following the 0, 10, and 20 cm topsoil depth removal respectively. The organic carbon levels in the 0 to 10 cm depth of the Gray Luvisol were 33.8, 18.0, and 8.5 g kg^{-1} following the 0, 10, and 20 cm topsoil depth removal. Removal of 10 cm of Ap from the Gray Luvisol resulted in removal of almost one-half of the organic C compared to control whereas the proportion lost in removal of 10 cm from the Black Chernozem was somewhat smaller.

There is a relationship between topsoil depth and yield or productivity as described in the previous section. Although SOM is not the only soil constituent lost upon erosion or soil removal, it is a major contributor to lost productivity of eroded soils. The data provided relative correlation of yield with topsoil depth loss is applicable to the correlation between organic matter (organic carbon) loss and yield reduction.

The requirement to replace 90% of the average pre-construction or control topsoil depth for the period post April 1, 2004 suggests that 90% of the organic matter is retained in the replaced soil. Similarly, the topsoil replacement requirements of 80% and 70% for the different time periods correspond to the ≤ 20% and ≤ 30% decrease in total organic carbon respectively.

For sites assessed (regardless of construction dates for new assessments or constructed after April 1, 2004) topsoil organic carbon loss is to be assessed and compared with organic carbon content data from control locations or pre-construction site data. One approach to assessing change in organic carbon levels or comparing offsite to on site carbon levels is a comparison of carbon concentrations. This approach would involve comparison of carbon concentration data from a series of samples obtained on site and from control or pre-construction sampling. This sampling approach would allow for subsampling from a larger number of locations using the same protocol as described for assessment of texture (clay content) outlined later in this document. However, the values generated from this sampling approach do not describe quantitative C losses or changes because mass of C per unit volume of field soils also depends on bulk density (see Section 3.4.4.2) and the soil horizonation (Ellert et al. 1999). When C concentrations are identical the amount of C stored in a fixed soil thickness or volume varies in direct proportion to soil bulk density. Since C storage is expressed as mass per unit area to a specific depth comparisons among on site and offsite locations will be based on the same soil thickness or volume and determination of soil bulk density. Soil bulk density is the ratio of the mass (g) of an oven-dry soil sample to the volume (cm^3) of that sample at a specified moisture condition, e.g. field moisture, 1/3 bar, oven-dry, etc. (McKeague 1978).

Errors can arise if bulk density estimates are made independently of C concentrations. Therefore, bulk density should be calculated from the same core or sample used to determine C concentration. This approach does not allow for a large number of samples to be obtained due to the methodology associated with bulk density sampling, which requires obtaining a precise volume of soil. Therefore, one sample will be obtained at five locations (one from each of four quadrants and the well center) and from four control locations. The method to be used for determining bulk density is a modified version of the core method and associated calculations described by McKeague (1978).

The emphasis is on collecting a fixed volume of soil that can be placed into a plastic bag rather than attempting to preserve a core. Samples will be obtained to a depth of 15 cm on site

and in the control or pre-construction locations. The inside diameter of the core unit used must be determined to provide an accurate measure of the volume of soil obtained. A moisture content of the entire sample is determined and total organic carbon will then be determined by dry combustion (Leco Induction furnace) (McKeague 1978). For samples containing carbonates that are identified primarily by pH (values > 7.0), organic C will be determined by subtracting carbonate C from total C. Carbonate C is determined by the technique of Bascomb (1961).

The total organic carbon content calculated on the basis of bulk density and a 15 cm depth for the five on site sampling locations will be compared to the mean value for the four controls or the mean value for the five locations sampled in the pre-construction site assessment. A simplified approach to calculating the amount of total organic carbon in the upper 15 cm of soil in one hectare would be: dry bulk density (g/cm^3) x 15 x % TOC = t TOC/ha. For sites assessed (regardless of construction date for new assessments) or sites constructed after April 1, 2004 a maximum decrease in total organic carbon ≤ 10% of the amount reported in the pre-construction site assessment or controls is allowed. For sites constructed during the period April 1, 1983 to April 1, 2004 a maximum decrease in total carbon in the replaced topsoil compared to controls is allowed. For sites constructed prior to April 1, 1983 a maximum decrease of ≤ 30% in total organic carbon in the replaced topsoil compared to controls is allowed. If any of the well center grid or four quadrant locations, excluding the area represented by the well center grid fail, then the entire site fails.

3.4.3.2 Texture – how and if it should be used for quality assessment. Many stakeholders and the industry and consulting staff in particular, expressed dissatisfaction with the current texture criteria of dropping a class when texture changes from one class to another. Typically, when developing or using criteria where numbers or lines on a graph are used, the "transition" area just below or above the "limit" creates some debate. For example, what is the difference in soil capability between a soil with 38% clay vs 42% clay? According to the current criteria the latter soil would drop a class in quality. Another major concern relates to the fact that hand texturing results in a great deal of subjectivity and variability in measurement due to moisture content.

Most individuals preferred to see a tolerance of change in clay content allowed. A review of the soil quality literature resulted in no reference to work undertaken to determine the impact of textural change in the context of "admixing" or increase in clay content on

productivity or capability. Some researchers (Reinl 1984; McGill et al. 1988) reported that cultivation dilutes the concentration of SOC in surface soils by mixing organic matter rich A horizons with the underlying B horizons. They recommended that land management practices that avoid dilution of SOC should be strongly encouraged.

Increases in clay content in the topsoil layer have a bearing on aggregate size and strength with both size and strength increasing with increasing clay levels.

The criteria recommend a change (maximum increase) of $\leq 8\%$ in clay content for the on site surface soil or topsoil compared to pre-construction or control data. This value is based on a review of the clay content ranges for the various classes in the texture triangle and a series of calculations of soil horizon mixing scenarios based on the criteria related to the required soil replacement depths. It is recognized that the source of the clay may have different effects on the overall topsoil properties. For example, clays from C horizons may be different than those from B horizons. However, it would be impractical to attempt to distinguish between the different clay sources.

For sites assessed (regardless of construction dates for new assessments) or constructed after April 1, 2004, particle size analyses will be conducted on five samples collected from five locations on the site – one from the well center grid and one from each of the four quadrants of the site, excluding the area represented by the well center grid. Each of these five composite samples will be comprised of a minimum of three subsamples. Four samples will be collected from the control locations for comparison to the site values.

This sampling protocol represents a compromise approach to assessing variability over the site as well as maintaining the number of samples analyzed to a reasonable number. Collecting one sample from each of the 25 grids may result in getting a better indication of variability across the site but the level of information gained likely does not justify the increased cost in sampling time and analytical work.

The clay content for each of the five on site sampling locations will be compared to the mean clay value for the four controls or the mean value for the five locations relative to the pre-construction site assessment. An increase in clay content >8% on site compared to the pre-construction site data or control data will result in failure. If the well center, or any of the four quadrant locations excluding the area represented by the well center grid fail, the entire site fails.

The particle size analysis technique will be that of Gee and Bauder (1979).

3.4.3.3 Aggregate Size and Strength. The discussion regarding aggregate size and strength is extracted from The Manual for Describing Soils in the Field (Expert Committee on Soil Survey 1982) and the Canadian System of Soil Classification (Agriculture and Agri-Food Canada 1998).

Soil structure refers to the aggregation of primary soil particles into compound particles which are separated from adjoining aggregates by planes of weakness. The classification of structure involves consideration of the shape and arrangement, the size, and the distinctness of the visible aggregates or peds. An individual natural soil aggregate is referred to as a ped. The four main types of structures include:

- **structureless** – no observable aggregation or definite orderly arrangement around natural lines of weakness. This is often associated with relatively coarse textured soils including sands and gravels
- **blocklike** – soil particles are arranged around a point and bounded by flat or rounded surfaces. The blocklike type includes three kinds: angular blocky, whose faces are rectangular and flattened, bounded by planes intersecting at relatively sharp angles; subangular blocky, whose faces are subrectangular, or consist of mixed rounded forms; and granular, which are spheroidal, characterized by rounded vertices
- **platelike** – soil particles are arranged around a vertical axis and bounded by relatively flat horizontal surfaces. This is the structure typically associated with Ae horizons
- **prismlike** – soil particles are arranged around a vertical axis and bounded by relatively flat vertical surfaces.

More details pertinent to structure are provided in the two references listed at the beginning of this section. For the purposes of these criteria the term "aggregate" will be used to refer to the "particles" that constitute the soil. In the case of the surface of cultivated soils the aggregates are a representation of the "clods" that are formed as a result of some disturbance such as cultivation.

Soil consistence is the property of soil materials that relates to the degree and kind of cohesion and adhesion or to the resistance to deformation and rupture (soil strength). Every soil material has consistence irrespective of whether the mass is large or small, in a natural condition or greatly disturbed, aggregated or structureless, or moist or dry. Although consistence and structure are interrelated, structure deals with the shape, size, and definition of natural aggregates

that result from variation in the forces of attraction within a soil mass, whereas consistence deals with the strength and nature of the forces themselves.

Soil consistence is described in terms of the resistance of soil material to failure under stress, the behavior of soil material when it fails or deforms under stress, the capacity of soil material to change shape under stress and to regain the original shape after removal of the stress, and the capacity of the soil material to adhere to foreign objects.

Terminology for consistence includes separate terms for description at three standard moisture contents including dry, moist, and wet. Soil consistence for moist and dry moisture states is estimated under field conditions by estimating the soil strength (resistance to crushing offered by an unconfined volume of soil in the field). The following definitions are provided for wet, moist, and dry consistence.

Wet Consistence (Stickiness)

Nonsticky – After the release of pressure, practically no soil material adheres to the thumb and finger.

Slightly sticky – After pressure has been applied, the soil material adheres to both the thumb and finger, but comes off one or the other rather cleanly. The soil is not appreciably stretched when the digits are separated.

Sticky – After pressure has been applied, the soil material adheres strongly to both the thumb and forefinger and tends to stretch somewhat and pulls apart rather than pulling free from either digit.

Very sticky – After pressure has been applied, the soil material adheres strongly to both the thumb and forefinger and is decidedly stretched when they are separated.

Moist consistence

Loose – The soil material is noncoherent.

Very friable – The soil material is crushed under very gentle pressure, but coheres when pressed together; the specimen fails under less than 8N of force (very gentle pressure).

Friable – The soil material is easily crushed under gentle to moderate pressure between the thumb and forefinger and coheres when pressed together; the specimen withstands 8N, but fails under 20N (gentle pressure).

Firm – The soil material is crushed under moderate pressure between the thumb and forefinger, but resistance is distinctly noticeable; the specimen withstands 20N but fails under 40N (40N of force corresponds to firm pressure between the extended thumb and forefinger of many people, but it is considerably less than the maximum force that can be exerted slowly).

Very firm – The soil material can be crushed between the thumb and forefinger, but strong pressure is required; the specimen withstands 40N but fails under 80N (80N of force is near the maximum force that can be exerted between the extended thumb and forefinger for many people).

Dry Consistence

Loose – The soil material is noncoherent.

Soft – The soil material is weakly coherent and fragile, and breaks to a powder or individual grains under very slight pressure; the specimen fails under less than 8N of force (very gentle pressure).

Slightly hard – The soil material is weakly resistant to pressure and easily broken between the thumb and forefinger; the specimen withstands 8N of force but fails under 40N (40N of force corresponds to firm pressure between the extended thumb and forefinger of many people, but is significantly less than the maximum force that can be exerted slowly).

Hard – The soil material is moderately resistant to pressure; it can be broken in the hands without difficulty, but considerable pressure is necessary to break it between the thumb and forefinger; the specimen withstands 40N of force but fails under 80N (80N of force is near the maximum force that can be exerted between the extended thumb and forefinger of most people).

Very hard – The soil material is very resistant to pressure; it can be broken in the hands only with difficulty, and is not breakable between thumb and forefinger; the specimen withstands 80N of force but fails under 160N (160N of force corresponds approximately to the force that can be applied slowly with a foot or by compression between two hands).

Extremely hard – The soil material is extremely resistant to pressure and cannot be broken in the hands; the specimen withstands 160N of force but fails under 800N (800N of force is near the pressure of full body mass for many people).

Rigid – The soil material cannot be broken except by extreme pressure; the specimen withstands 800N of force.

For the purposes of the criteria the wet consistence classes used will include nonsticky, slightly sticky, sticky, and very sticky. For moist consistence the classes will include loose, friable, firm, and very firm. For dry consistence the classes will include loose, soft, slightly hard, hard, and very hard.

Aggregate Size

The aggregate sizes associated with the different soil structures are as follows:

Granular

fine	<2 mm
medium	2 to 5 mm
coarse	5 to 10 mm

Platy

fine	<2 mm
medium	2 to 5 mm
coarse	>5 mm

Blocky (angular and subangular)

fine	<10 mm
medium	10 to 20 mm
coarse	20 to 50 mm
very coarse	>50 mm

For the purposes of the criteria the size classes described above will be simplified. In many situations one is comparing the aggregate size of the surface soil or topsoil layer of cultivated soils or the replaced soils on the wellsite or area of disturbance with the offsite control locations. The classes will remain as in the 1995 criteria; <2 cm, 2 cm to 5 cm, and >5 cm to

10 cm. The aggregate size must remain in the same class and no aggregates >10 cm are allowed unless similar size soil aggregates occur in the control locations.

3.4.4 Soil Profile Assessment – how and where to assess?

There was a relatively small amount of feedback on this topic compared to the other components of the criteria. Profile restrictions can occur in a wide range of soil textures, however they most commonly occur in the finer textured soils that are dominant in the Peace River and Grande Prairie regions. Penetrometer resistance and bulk density determinations are physically based methods with which to assess profile restrictions.

3.4.4.1 Cone Penetrometry. Cone penetrometers, devices used to measure the penetration resistance of soils, have been in use for many years, and have had varied applications in many fields because of their easy, rapid and economical operation (Perumpral 1987). The potential value of penetrometers in assessing compaction has long been recognized. For example, Richards (1941) stated that a penetrometer should be able to demonstrate quickly and easily whether or not a compacted layer of soil occurs at or below the plow depth, regardless of whether such a compacted layer occurs naturally, or may be the result of plowing at the same depth repeatedly, or of tractor wheels running in the furrow. Perumpral (1987) stated that penetrometers were popular because: (a) they are quick, easy, and economical; (b) their data can be analyzed easily; and (c) they are good tools for investigating sands where undisturbed sampling is difficult. One disadvantage he stated, however, is that they provide no samples for direct observation or other analyses. The penetrometer is a useful tool in field investigations, especially as an aid in soil diagnosis. While penetrometer records may not lend themselves to precise descriptions, they assist in discovering the reasons for noted differences in, for example, crop yields or percolation rates.

The cone penetrometer, which has a cone-shaped tip with a 30 to 60° angle and the pocket penetrometer, which has a blunt tip, are the two types of penetrometers used in soils research (Cassel 1982). Cassel (1982) found that the pocket penetrometer was useful for qualitatively detecting horizons or zones of either high or low mechanical impedance (MI) in soil profiles but Cassel (1982) suggested that the pocket version is not suitable for quantitative studies due to difficulty in sustaining a uniform penetration rate, reading the scale and accurately determining when the tip has penetrated 0.3 cm into the soil.

A cone index of 2 MPa corresponds to soil strengths that cause root restriction (Blanchar et al. 1978) and 3 MPa has been interpreted as a total barrier to root growth in the absence of macropore channels (Busscher et al. 1986). Values as high as 20 MPa at water contents of 10.7% have been measured (Karlen et al. 1990, unpublished data). Therefore, cone indices have sometimes been determined after rains had wet the profile (Sojka et al. 1990).

Penetration resistance is a function of several soil properties such as bulk density and soil water content or tension. Penetration resistance is also referred to as MI or generally in agricultural engineering circles, as cone index (CI). CI is defined as the force required to push a metal cone into the soil, divided by the basal area of the cone (Davidson 1965). In general, soil strength and thus cone index increase as the silt and clay content increase, soil moisture decreases, depth increases and bulk density increases. Penetration tests conducted in sandy clay loam and clay loam soils showed that the dependency of maximum penetration resistance on bulk density was greater at lower moisture levels than at higher moisture levels (Mulqueen et al. 1977). These researchers concluded that the penetrometer is useful (as it gives results quickly and easily) for comparing the relative strengths of soils under conditions of similar moisture content and structural state, but in other cases, supplementary measurements (such as moisture content) must be made.

Several researchers have suggested taking supplementary analyses to interpret or normalize penetrometer measurements (e.g., Carter 1967; Cassel 1982; Busscher 1990) and thus increase their utility. However, having to collect such ancillary data would likely negate the value of the penetrometer as an instrument to detect soil compaction quickly, easily and inexpensively. Most of the changes in these parameters would result from the treatment generally being examined, and hence the penetrometer would merely be integrating the effects of all these parameters, indeed what a researcher is looking for.

With regard to assessment of reclamation success, many of the factors affecting penetrometer resistance will or should vary little between the control and reclaimed area. Because precipitation and evapotranspiration rates on and off the reclaimed area should be similar, soil moisture should also be similar. Thus *differences* in penetrometer resistance between the reclaimed and control area should be largely due to compaction and/or textural changes. Accordingly, relative penetrometer resistance is recommended as an inexpensive and convenient means to identify areas requiring further assessment of potential profile restrictions.

3.4.4.2 Bulk Density. Bulk density is easily measured and is commonly reported for field and laboratory studies (Cassel 1982). It is perhaps one of the most universally reported soil physical parameters, and is used widely to draw inferences on other soil properties like porosity or on soil processes like infiltration. It is widely measured as a response variable in grazing and tillage studies. It is routinely measured by soil scientists, agronomists, agricultural engineers and civil engineers, to name a few, although their actual use of the parameter might differ. Although a simple parameter by nature, its measurement requires the accurate measurement of soil volume, which is a more challenging component than moisture content in a field scenario. Soil compactness has often been expressed in terms of bulk density. Bulk density data are readily interpretable for fundamental soil properties and for properties that affect plant growth.

Many methods have been proposed for measurement of bulk density; some are very old, and others are relatively new.

Group A. Methods requiring removal of a known volume of undisturbed soil.
1. Core methods
2. Coated samples (often referred to as clods in the literature)
3. Excavation methods

Group B. Methods depending on conduction of high-energy x-rays and gamma rays by soil *in situ*.
1. X-ray diffraction and absorption
2. Gamma ray scattering and absorption

For practical reasons only the Group A methods are further discussed here.

Core Methods

This method uses the mass of the soil removed from the known volume of a core cylinder (Blake 1965). Core sampling is a simple, straightforward method for measuring bulk density. Cylinders of known volume are driven into the soil and the resultant soil core weighed (Page-Dumroese et al. 1999). Cores having diameters of 4 to 8 cm are generally most common (Cassel 1982). Uhland (1949) utilized soil cores, 3 inches in diameter and 3 inches high, obtained in aluminum cylinders, by means of a sampler patterned after the type described by Yoder (1936) and modified and improved by the researcher. The Uhland corer has received wide acceptability (e.g., McKeague 1978).

The presence of rock fragments (material > 2 mm in diameter) generally leads to a field-measured soil bulk density that is higher in value than the fine soil density (material <2 mm in

diameter) alone. The difference between fine and whole soil bulk density in cultivated soils with few rock fragments is of minor importance (Elonen 1971), but with increasing rock fragment content, it becomes significant in many forest soils (Terry et al. 1981; Childs 1982). The difference is important because bulk density of the fine soil correlates well with root growth (Minore et al. 1969; Keisling and Smittle 1981), soil aeration (Keisling and Smittle 1981), volumetric soil water content (Flint et al. 1981) and soil water release properties (Childs 1982).

In very stony or cobbly soils sampling with metal cylinders is commonly impractical if not impossible. When the cutting edge of a cylinder driven into the soil encounters rocks about 5 or more cm in diameter the cylinder is usually damaged and the sample has to be discarded. Even if the rock is only 1.5 to 2.5 cm in diameter the cylinder is likely to be damaged and the rock is either pushed outward, leaving a void in the sample, or pushed inward, compressing the sample. Consideration of these difficulties, which are frequently encountered in forest soils, is important (Lutz 1944). For these reasons, determination of bulk density in soils containing high proportions of coarse fragments usually relies on displacement methods for estimation of soil volume (e.g., Flint and Childs 1984).

Clod Methods

Density measurements with the clod method use mass and volume of a natural clod or large ped (Flint and Childs 1984). Natural soil clods can be coated with saran resin and used to determine bulk density and water content at field and adjusted moisture levels. The chief advantage of using natural clods for these determinations is that the fabric of the soil undergoes a minimum of change during sampling and subsequent laboratory operations.

Tisdall (1951) reported that the clod method usually gives higher bulk density values than other methods, perhaps because it does not take inter-clod space into account. Blake (1965) and Shipp and Matelski (1965) suggested that this method often yields a high bulk density value because measurement can exclude the natural pore space between clods and between clods and rock fragments. Values may also be higher because of bias towards firm, compact clods capable of withstanding disturbance during measurement. Although the clod can be crushed and sieved to determine rock fragment content, measured values are often low (Shipp and Matelski 1965). Culley (1993) inferred, based on a review of Blake and Hartge (1986), that the technique was 'not very precise'.

Because there are practical problems with obtaining, transporting and efficiently processing clods, as well as interpretational difficulties with data generated by the clod method, it is not recommended for application in routine reclamation work.

Excavation Methods

The excavation technique appears to have the widest application for stony soils where the core technique is difficult, if not impossible, to utilize. Volume excavation is an appealing alternative to core techniques because it allows for flexibility in volume of soil sampled based on size of soil coarse-fragments. Bulk density is determined by dividing the mass of soil excavated from an irregular hole by the volume of that hole. The volume of the hole is determined by filling it with a material of known density or volume. A variety of media are used to determine the volume of soil cavity extracted, including water (Israelson 1918), sand (Frear and Erb 1920), viscous fluids (Beckett 1928), plaster of paris (Lutz 1944), beads (Flint and Childs 1984), rubber balloon (Blake 1965) and expanding polyurethane foam (Muller and Hamilton 1992). Water is the most common (Kohl 1988, as cited in Page-Dumroese *et al.* 1999), however, considerable experience and success has been reported with sand and beads.

The sand cone excavation technique was designed specifically for gravelly soils (Blake 1965). In the sand cone procedure the soil is excavated and a weighed sand dispenser inverted over the irregular hole. Sand flows from the dispenser to fill the hole and then the volume of the hole is calculated from the difference in mass of sand and bulk density of the sand. Compaction of sand during the measurement is a problem that has been addressed to a large extent by standardization procedures recommended by ASTM (1982b). Soils with large coarse fragments require large amounts of sand, which poses a practical problem. For this reason, ASTM (1982b) limits the sand cone procedure to soils with rock fragments < 50 mm diameter.

Measurements with water require covering the hole with an impermeable, flexible liner (Shipp and Matelski 1965; Howard and Singer 1981; ASTM 1982a). The liner, which could be a very thin sheet or bag of polyethylene, is pressed tightly against the wall and bottom of the hole, and the weight of the water holds it in place. The water could be used over again, so that only a small amount would have to be carried about. Where plastic liners are used, protruding stones and roots must be removed from the hole surface to avoid puncturing the liner (Howard and Singer 1981).

Water techniques require that a bench be cut into soils on sloping terrain to create a level surface. Since soil horizons generally form parallel to the soil surface (Alexander 1977), proper sampling becomes difficult, if not impossible, for shallow surface horizons on sloping terrain. The excavation technique can be used on moderate slopes if sand is used to measure volume.

The bead cone method is a modification of the sand cone, irregular hole excavation technique used for measuring soil bulk density (Flint and Childs 1984). The technique is designed for use on steep, remote sites with appreciable rock fragment contents. The bead cone apparatus can measure the volume of an irregular hole with an accuracy of 1% and samples a large enough volume to allow measurement on soils with rock fragments up to 85 mm in diameter. The sampler requires initial calibration in order to establish its exact dimensions and the packing behavior of the epoxy spheres used to measure volume. After this, the sampler can be used without daily calibration because calibration constants do not change with time.

Summary

Soil bulk density is a fundamental physical property that can be used to assess and interpret suitability for plant root systems; high bulk densities restrict root growth. Like penetrometer measurements, bulk density is an appropriate method for identification of areas that require further assessment for profile restrictions. Bulk density is also a required measurement for converting soil concentration data to mass per unit area (see Section 3.4.3.1).

Undisturbed cores are the preferred practical method for measuring bulk density in soils with low coarse fragment contents. Where coarse fragments are a problem, displacement methods are recommended. Water displacement is likely most practical for remote sites. Where stony/rocky soils are situated in steep terrain bead cone methods are appropriate.

3.4.5 Gravel and Rocks – are the sizes and allowance reasonable and understandable?

There were no concerns raised by stakeholders regarding this parameter. If visual assessment indicates that there may be a problem then measurements are undertaken.

Gravel and rocks have a negative impact on soil quality. They decrease the number of germination sites or the density of plant cover that can be established on a site. They also obstruct rooting channels and reduce the water holding capacity of the soil.

Agricultural practices are particularly impacted by gravel and rocks as they damage equipment in addition to the impacts described above. For these reasons the criteria for cultivated lands allow a maximum increase of 10% for gravel and no increase for rocks. The rationale is that rocks negatively affect soil quality and can be easily picked or removed from the site to achieve the criteria defined.

The criteria for grasslands allow a maximum increase of gravel plus rocks of 10% or 20% depending on the time of site construction. The criteria for forested lands in the white area allow for an increase of 20% in surface cover for both gravel and rocks.

One comment received related to the fact that rocks can be "dragged" off the site and onto the undisturbed adjacent land by farm machinery.

3.5 THE USE OF AMENDMENTS (STRAW, MANURE, OTHER) TO IMPROVE TOPSOIL QUALITY

Most individuals felt that the use of amendments can be beneficial provided that application rates are reasonable. In some situations application rates have been too high and at some locations amendments have been used to fill in depressions or areas of subsidence. Some input provided suggested that composted manure is a superior product and that it will have a more sustainable benefit than any other amendment. A review of the literature relative to the use of amendments was completed and some of the relevant information follows.

Wallace and Terry (1998) define a soil conditioner as "a substance that improves the physical properties of soil. Soil conditioners include both synthetic and natural products... The general use of the term amendment usually implies substances that enhance any and all of the physical, biological, and nutritional properties of soil." Slick and Curtis (1985) define an amendment as "an organic or inorganic material, such as lime, fertilizer, or manure that is incorporated into the soil "root zone" to make it productive or more productive of vegetation." Regardless of definition or term, application of organic or inorganic matter to the soil is done to increase the productivity of the soil, whether it be to enhance the chemical, biological, or physical aspects of the soil. Often, it is not possible to separate the three categories, as there can be considerable overlap (Wallace and Terry 1998).

In their book, Wallace and Terry (1998) include various sources of materials that can be used as soil amendments. These include: municipal solid waste such as recycled organic

material; animal and crop production residues and sewage sludge (biosolids), including manure, bone meal, spent mushroom compost, etc.; industrial by-products such as gypsum, lime, fly ash, coal ash, wood ashes, plasterboard gypsum, recycled plastics, etc. Each product can improve the physical properties of the soils to a different extent.

Soil conditioners and amendments are most often used when soils have been subject to adverse situations including erosion, compaction, loss of organic matter, chemical threats, and biological breakdown, and they are now being more frequently used for reclamation of disturbed lands.

Manure, straw, hay, and peat have been used as amendments for wellsite reclamation for many years. These materials have been used to increase organic matter content, improve soil tilth, soil porosity, water holding capability, nutrient levels, and overall productivity. They have also been used for remediating hydrocarbon contaminated sites. Straw, hay, and peat are useful for amendment of physical properties but require the addition of fertilizer to support the decomposition or breakdown and not result in nitrogen immobilization.

Feedback from the stakeholders indicated that amendments can be beneficial provided that they are used appropriately. In many situations excessive rates have been applied resulting in site management problems. One of the major concerns regarding the use of amendments has been their overall sustainability. Alberta Environment (1996) states, "manure and other organic amendments are NOT topsoil replacements. They are generally considered to be short-term soil physical amendments".

Larney et al. (2001a) conducted a study of topsoil replacement and organic amendments for oil wellsite reclamation at sites in the vicinity of Strathmore, Hesketh, and Rosedale, Alberta. The soil depth treatments included 0%, 50%, 100%, and 150% replacement. The amendment treatments included fresh cattle manure, composted cattle manure, wheat straw, alfalfa hay, and check. Manure and compost were applied at 40 Mg ha^{-1} (dry weight basis). Wheat straw and alfalfa were applied at the maximum rates that would permit proper incorporation and seedbed preparation. Amendments were incorporated with two passes of a rototiller. Spring wheat was the test crop at all three sites throughout the four year study period. Plant density, plant height and maturity, plant biomass, grain yield, straw yield, harvest index, plant nutrients, soil water, and soil nutrients were assessed.

A number of observations were made throughout the term of the study. Overall the results indicated that the application of topsoil was beneficial for crop growth but that diminishing returns occurred at high topsoil replacement depths. The study demonstrated that organic amendments can substitute for topsoil, at least in the short-term (4 years). They also state that the addition of nitrogen, phosphorus, and carbon by organic amendments is an important mechanism in building soil productivity on disturbed soils. A question remains regarding the longevity of the restoration effects found in the first four years of the study (Larney et al. 2001a).

Larney et al. (2001b) reported the addition of manure at 48 Mg ha^{-1} in 1990 sustained wheat yields higher on topsoil removal treatments of 5 cm and 10 cm depth for eight growing seasons. They go on to state that after 11 growing seasons, the average yield of treatments where 10, 15, or 20 cm of topsoil had been removed and then amended with manure was 87% of that on the 0 cm or check treatment.

Weeds can become a problem resulting from the use of straw, hay, and manure. Composting manure for example, will destroy weed seeds and limit the problem.

Wood residues such as wood chips, shavings, sawdust, hog fuel, and burner ash have been used as soil amendments. Buck (1998) reported on a study undertaken to evaluate the use of mill by-products for soil amendment purposes. He concluded that the higher additions of high carbon by-products tended to reduce barley growth and yields in year one and that addition of an organic nitrogen source such as manure to the by-product appeared to moderate the reduction in barley yields.

Research relative to land application of mechanical pulp mill sludges in Alberta was initiated by the Alberta Research Council in 1991. Since that time several studies have been undertaken to demonstrate that the sludge is an effective and environmentally safe soil amendment. All of the studies conducted have demonstrated enhanced crop and tree growth and that this benefit is sustainable for five to ten years and more.

Macyk et al. (2003) assessed the sustainability of carbon and nitrogen levels in soils amended with mechanical pulp mill sludge. The carbon, nitrogen, and phosphorus data obtained in the long-term monitoring of the agricultural field plot study, the forest cut-block experimental site, and the disturbed forest site were compiled. The data represented a record of nine to ten years of data for the various parameters. The trends observed at all three areas including an

agricultural crop site, a forest cut-block with re-establishment of lodgepole pine and white spruce following timber harvest, and a disturbed forest (reclaimed haul road) were similar.

Soil carbon and nitrogen levels were enhanced initially as a result of sludge application. These increased levels were maintained over the term of the trials to date. Plant available nitrogen and phosphorus values were consistently higher for the sludge amended treatments than the controls. These results confirmed that enhanced carbon and nitrogen levels will be maintained or will continue indefinitely as the sludge continues to break down and the nutrient cycling associated with the top and root growth continues.

Other studies implemented in 1997, 1998, and 2000 which include full-scale operational spreading in the forest and on agricultural land are also showing similar trends in terms of tree and crop productivity and carbon and nitrogen dynamics. The study undertaken to demonstrate the economic benefit of using sludge compared to chemical fertilizers provides detailed information regarding the plant available nutrient levels in the spring (prior to seeding) and fall (after harvest) for each year of the study (Macyk and Faught 2000).

The results of all the studies consistently demonstrate the sustainability of carbon and nitrogen levels in soil amended with mechanical pulp mill sludge. The sludge can be used as an amendment to ensure long-term productivity of disturbed or reclaimed sites as well as enhancing the productivity of normally cropped agricultural and forest soils.

It is also important to note that in addition to providing sustained levels of carbon and nitrogen, the sludge also improves soil moisture holding capacity and other physical properties such as porosity and tilth. For these reasons the sludge is an excellent soil amendment for use in achieving equivalent capability in reclamation of a variety of land disturbance including wellsites and associated facilities.

The information outlined above demonstrates that soil amendments can be used to restore soil productivity at disturbed sites including wellsites. Some of the examples demonstrate a sustainability of carbon and nitrogen levels for 10 years from the time of amendment with a projection of several additional years subsequently.

It must be noted that the objective of reclamation of wellsites and associated facilities is to achieve equivalent capability which means that the capability of the replaced soil must be maximized without management inputs such as amendments or fertilizer applications. In essence, the intent is to maximize soil conservation and minimize the use of amendments.

However, in situations where soil salvage was not a requirement, these materials can be extremely beneficial in re-establishment of capability and productivity and should be used.

In the situations where soil quality and soil quantity are limited one has to consider the implications and cost-benefit of "importing" soil vs the use of soil amendments to improve the site.

The Reclamation Criteria for Wellsites and Associated Facilities – 1995 Update (Alberta Environmental Protection 1995) made reference to soil amendments. Some stakeholders noted that while soil amendments were listed, no indication of amounts required or application rate were noted. In reality, the criteria cannot define absolute application rates because of the variability of the receiving soils or sites and the variability of amendments themselves. One might suggest that one of the simplest guidelines regarding application rate might be related to "the maximum amount that can be readily incorporated into the soil surface".

Criteria are in place regarding the recommended application rates of mechanical pulp mill sludge on agricultural land (Alberta Environmental Protection 1999). Enough research has been done by the Alberta Research Council to provide similar information for forest land and disturbed site reclamation.

In the case of manure there are several variables that need to be considered including the source of the manure (cattle, hogs, poultry, etc.), the nature of the manure in terms of straw content etc., and the age or stage of decomposition when applied. To properly define the application rate of a specific manure on a specific parcel of land one should be determining the fertility status of the receiving soil and the characteristics of the manure prior to application.

3.6 LANDSCAPE PARAMETERS

There were only a few minor comments made regarding the landscape parameters. One comment related to the fact that an uneven surface on a wellsite would be "leveled" or "smoothed" quite readily by cultivation. On the contrary, this would not occur as rapidly with zero-till cropping practices.

3.7 THE USE AND VALUE OF MANAGEMENT PLANS

The suggestion was made that the field inspectors were generally not in favor of the management plans. There was also some discussion of what reclamation options are available

when topsoil importing is not possible. The criteria or approaches defined for management plans are sound. The issues identified related more to acceptability of the concept as opposed to any problems with the criteria.

3.8 ALTERNATIVE ASSESSMENT TECHNIQUES

Existing soil and vegetation techniques were assessed to determine the potential for use in the criteria update process. In addition to a review of the soil capability systems in place, the "Farm Land Rating System" prepared by Alberta Municipal Affairs (1982) was reviewed. The ratings measure the ability of soil to produce crops, modified by climatic conditions and adjustments to reflect costs of operation under normal management practices for each of the various agricultural regions of the province.

The application of the rating system is accomplished by firstly identifying and describing the physical properties present in a specific property. A comparative numeric rating system has been established to represent the desirability of the identified physical properties of a subject property. This comparative rating system establishes how each specific property rates on a provincial basis. The rating is then multiplied by a regulated base rate and a regulated factor to form an assessment on a per unit of area basis.

Net Productivity Rating is the rating that remains after the rating deductions determined for surface depth, subsoil, surface texture, and miscellaneous have been subtracted from the Adjusted Rating established for the field.

Although this system provides an estimate of productivity based on land characteristics it does not include actual productivity measures. Measurements of texture, organic matter and other soil parameters would also be required. While this system is effective in providing a relative assessment value for land and its productivity potential, it would require some modification/adaptation to meet the needs of the more site specific assessment requirements for wellsites and similar disturbances.

4. REQUIREMENTS IN OTHER JURISDICTIONS

4.1 SITE AND SOIL ASSESSMENTS

A literature search of site assessment techniques and reclamation success assessment techniques in other jurisdictions was completed. The information pertinent to vegetation monitoring is provided in the following section of this document. Very little information pertinent to upstream oil and gas was found with the exception of the regulations pertinent to oil and gas explorations, wellsites, and pipelines in the agricultural land reserve in British Columbia. The requirements defined by these regulations, which are provided below, are similar to the Reclamation Criteria for Wellsites and Associated Facilities – 1995 Update (Alberta Environmental Protection 1995).

4.1.1 Site Assessment Requirements

The soils of the surface leases must be documented prior to construction so that the reclamation of the land can be planned effectively. Surface lease means all leases, easements, and rights-of-way, which may be required for a wellsite, access road, or pipeline.

It is recommended that the owner of the development be familiar with the Weed Control Act and its regulations to ensure that the construction, management, and reclamation of the surface lease is in compliance with this Act.

The level of effort required to conduct site assessments will vary depending on local conditions, but the following requirements are the minimum information that must be filed with the Provincial Agricultural Land Commission and the owner of the land:

Site Information:

- well name and wellsite approval number
- petroleum company
- location and legal description of property
- name and address of landowner
- date of site inspection
- name and address of person conducting site assessment

Site Description:

- a brief description of the surficial geology. This information is available from published soil surveys and government reports.
- the agricultural capability rating from published resource inventory maps, such as the Canada Land Inventory maps.
- a rating of the surface drainage as good, moderate, or poor.
- a description of the site topography, indicating the gradient and aspect of slopes.

Sampling Procedures:

The primary purpose of the site assessment is to document the soil quality, quantity, and profile of the surface lease. Soil sampling can be done with hand tools, an auger, or coring equipment. The following procedures must be followed:

- the soil conditions of a wellsite must be sampled at five locations: one sample must be taken 5 meters inside from each corner of the surface lease boundary, and one sample must be taken at the center of the surface lease.
- access roads and pipelines greater than 500 m in length require one sample on the centerline of the surface lease for every 250 m in length.
- soil samples must extend 20 cm below the B horizon, or to a maximum depth of 100 cm below the surface of the ground.

Soil Assessment – a visual analysis of the soil at each sample location must include the following information:

- Sample Number
- A horizon depth (cm) and description
- B horizon depth (cm) and description

The A horizon is the upper portion of the soil profile that has been significantly altered by accumulation of organic matter and by weathering processes. This layer is commonly referred to as "topsoil". The B horizon is the soil layer below the topsoil that has been altered by weathering but has little or no visible accumulations of organic matter.

The description of each horizon must include its texture class based on the Canadian Soil Classification System.

The A horizon from the five samples from a wellsite must be combined and thoroughly mixed. A portion of this combined sample must be sent to a laboratory for an analysis of its organic content, pH, and texture.

Photographs – Photographs must be taken which show the condition of the surface of the lease prior to disturbance. Each photograph should be labeled with the date and WA#, and should be numbered so that additional information can be summarized in a table that includes the following columns: photo #, location, direction, and comments.

Sketch Map – The site assessment must include a sketch map of the surface lease which shows the following information:

- location of where the soil samples were taken
- location and direction of the photographs
- boundaries of the wellsite, access road, and pipeline right-of-ways
- current vegetation and land use
- topographical features such as slope direction and drainage patterns
- location and description of work required to prevent soil erosion from runoff

4.1.2 Site Reclamation Requirements

The purpose of the following requirements is to ensure that the soil, topography, and vegetation of surface leases are restored to their original or better conditions after wells have been decommissioned and pipelines have been installed. Surface lease means all leases, easements, and right-of-way, which may be required for a wellsite, access road, or pipeline. The requirements do not address site contamination and the disposal of wastes because these matters are the responsibility of other government agencies.

It is recommended that the decommissioning and reclamation guidelines published by the Canadian Association of Petroleum Producers in September 1992 be followed when restoring surface leases (B.C. Oil and Gas Commission 1995).

A report which documents that the following minimum requirements have been met must be filed with the provincial Agricultural Land Commission and the owner of the land prior to a Certificate of Restoration being issued by the Ministry of Energy, Mines and Petroleum Resources (Ministry of Energy, Mines, and Petroleum Resources, 1995), or within 18 months of installing a pipeline:

Definition of Surface Soil – For the purposes of Schedule B, surface soil means the soil which has been salvaged, amended, and replaced onto the surface lease.

Sampling Procedures:

a. Wellsite

No soil sampling is required for portions of the surface lease where no soil disturbance has occurred. Disturbance includes, but is not limited to, stripping, rutting, trenching, compaction, and erosion.

The quantity and quality of the replaced surface soil of a surface lease, must be sampled using a 20 m x 20 m sampling grid. The edges of the grid should correspond to the boundaries of the surface lease, and the grid should be adjusted evenly to cover the entire lease. A soil sample must be taken from the middle of each 20 m x 20 m grid, for each grid on the surface lease.

A minimum of four control samples must be taken from adjacent undisturbed ground; one each from the centerpoint of each side of the lease.

b. Access Roads and Pipelines

The quantity and quality of the replaced surface soil must be sampled at 250 m intervals for roads and pipelines >250 m in length, and a minimum of two sampling locations is required for roads and pipelines less than 250 m in length.

Two samples are required for each sampling location. One sample must be taken from the centerline of the surface lease, and one sample must be taken from undisturbed ground 10 m outside the boundary of the surface lease.

Soil Assessment:

Each soil sample must penetrate 20 cm below the surface soil, or to a maximum depth of 50 cm. A visual analysis of each sample of the surface soil must include the following information:

- Sample number
- Surface soil depth (cm)
- Description
- Admixing (%)
- Aggregate size

The description of each sample must include its texture class, based on the Canadian Soil Classification System. The extent of admixing (i.e., mixing of the B horizon into the A horizon) must be recorded. The admixing classes are: 0-10%, 10-20%, 20-30%, 30-40%, and >50%.

The aggregate size distribution for each sample of the surface soil must be recorded. The aggregate size classes are: <2 cm, 2-5 cm, and 5-10 cm. No soil aggregates greater than 10 cm are allowed.

The surface soil from five representative samples from a wellsite must be combined and thoroughly mixed. A portion of this combined sample must be sent to a laboratory for an analysis of its organic content, pH, and texture.

A visual analysis of each sample from undisturbed ground must include the following information:

- Sample Number
- A horizon depth (cm) and description
- B horizon depth (cm) and description

The description of each sample must include its texture, based on the Canadian Soil Classification System.

Soil Reclamation Requirements:

The following minimum reclamation standards must be met:

a. Depth of Surface Soil

- The required replacement depth (RRD) of surface soil is 80% of the depth of the average A horizon on the adjacent undisturbed ground
- The average replacement depth (ARD) is the average depth of all surface soil samples. The ARD must be equal to or greater than the RRD.
- The minimum replacement depth (MRD) is 80% of the RRD. All surface soils samples must be ≥ 80% of the MRD, except for surface leases which were originally covered by native trees or shrubs.

The MRD requirement does not apply where the average A horizon depth on the undisturbed ground is <10 cm, but the available surface soil must be replaced as evenly as possible across the entire surface lease.

b. Mixing of Soil Horizons

- The average admixing of all the surface soil samples must not be greater than 30%. That is, the average of the samples must be composed of less than 30% of non-surface soil (B horizon).

c. Soil Structure

- The average aggregate class of the surface soil samples must be the same as the average aggregate class of the samples from the undisturbed ground.
- The bulk density of the subsoil of the disturbed ground for each sampling location must not be more than 120% of the average bulk density of the subsoil of the undisturbed ground.

Topographic Requirements:

The topography of the surface lease must be restored to its original or better condition. The reclamation of the surface lease is to be assessed by comparing the reclaimed site, as a whole, with adjacent undisturbed ground. The following requirements must be met:

Drainage - surface drainage must be consistent with the original patterns, directions, and capacity, or be compatible with the surrounding landscape;
- facilities and structures left in place must not impede surface drainage.

Erosion - the frequency and extent of erosion features must be similar to adjacent undisturbed land.

Contour - the contour of the surface lease must conform to adjacent land or be consistent with present or intended land uses.

4.2 VEGETATION ASSESSMENTS

A literature search of potentially applicable methodology regarding vegetation performance was undertaken. Many of the papers were related to rangeland assessments which is not directly applicable to the vegetation assessment criteria for cultivated land but is included here and will be used in the overall update of the Reclamation Criteria for Wellsites and Associated Facilities – 1995 Update (Alberta Environmental Protection 1995). As well, there is not a great deal of literature pertinent to wellsite reclamation, reclamation/revegetation activities, and regulatory criteria associated with the oil and gas industry. Some information is available from British Columbia and Saskatchewan and from some jurisdictions in the USA.

The bulk of the information regarding assessment of vegetation performance on disturbed lands is associated with surface coal mining activities in the United States.

The Saskatchewan Petroleum Industry/Government Environmental Committee (SPIGEC 1999) developed some general guidelines for restoration of well sites and associated facilities on cultivated land as described below.

> The reclaimed site will be capable of supporting vegetation. Revegetation may be carried out by the operator, or may be left to the landowner. Revegetation is defined as establishment of a self-sustaining vegetative cover on the reclaimed land surface. The vegetative cover will be compatible with surrounding species. The objective of successful revegetation on reclaimed cultivated lands will be a crop condition equal to adjacent undisturbed croplands in the third crop season. The objective of successful revegetation on reclaimed range, pasture and haylands will be a vegetative cover equivalent to adjacent undisturbed land after three full growing seasons.
>
> Vegetation will be sustainable under reasonable farm management. Weeds will be controlled during restoration and there will be no noxious weed present on the site.
>
> Indicators of successful restoration:
>
> - similar plant cover, height, density, vigour and/or productivity as adjacent land;
> - no extraordinary efforts (fertilizer, management, etc) required to manage the restored area;
> - weed population similar to that found off site.

In British Columbia the Oil and Gas Commission oversees the restoration of disturbance associated with drilling activities. Application for a certificate of restoration (COR) is submitted under the authorities of the Petroleum and Natural Gas Act, Drilling and Production Regulation, and the Waste Management Act (B.C. Oil and Gas Commission 1995). Regulation 48 pertinent to surface restoration of wells and facilities states that "on completion or final abandonment of any well, test hole or facility installed for the purpose of exploring for, developing or producing petroleum or natural gas or processing natural gas, and as soon as weather and ground conditions permit:

- the area must be cleared of all refuse material
- waste petroleum must be removed
- excavations must be drained and filled
- unused concrete bases, machinery and materials must be removed, and

- the surface must be leveled and the site left in the condition as nearby as is reasonable to its condition when operations were commenced" (B.C. Oil and Gas Commission 1995).

Site reclamation requirements are outlined in the British Columbia Oil and Gas Handbook (Interim) (Energy Resources Division, Ministry of Energy, Mines, and Petroleum Resources 1995). Soil reclamation requirements, topographic requirements, and vegetation requirements are outlined.

The reclamation of a surface lease includes restoring vegetation by either replanting native vegetation or applying a certified seed mixture. The primary purpose of restoring vegetation on the surface of the lease is to prevent soil erosion and this should be the main criteria when choosing a certified seed mixture.

The reclamation of the surface lease is to be assessed by visually comparing the reclaimed site as a whole, with adjacent undisturbed ground. According to the BC Oil and Gas Handbook (Interim) (Ministry of Energy, Mines, and Petroleum Resources 1995) the following requirements must be met within 18 months of applying the seed mixture or introducing vegetation:

Table 1. Vegetation requirements to be met within 18 months of reclamation.

Criteria:	**Requirement:**
Species	* species chosen should be compatible with the vegetation on the undisturbed ground. * The seed mixture must be certified and not contain weeds.
Density	* ≥80% of the density on adjacent undisturbed ground.
Height	* ≥80% of height on adjacent undisturbed ground.
Health	* Plants should be healthy based on visual inspection of their vigour, height and color.
Cover	* The vegetation must cover ≥80% of the soil surface if the species on the reclaimed site are similar to the vegetation on the adjacent undisturbed ground. * Where the species composition on the reclaimed site is different from the vegetation on the undisturbed ground, or the undisturbed ground has been cultivated, vegetation on the reclaimed site must cover ≥80% of the soil surface. * Vegetation on the reclaimed site must be evenly distributed, or be similar to the distribution on the undisturbed ground.

The Oklahoma Energy Resources Board (OERB 2000) provides guidance regarding wellsite reclamation. Reclamation procedures include bringing all construction material back onto the well pad and reestablishing the natural contours where desirable and practical. The site should be prepared to provide a seedbed for reestablishment of desirable vegetation. Seeding and/or planting should be repeated until satisfactory revegetation is accomplished as determined by the Bureau of Land Management (1999).

The Utah Division of Oil, Gas and Mining, State of Utah, Department of Natural Resources (2001) developed "The Practical Guide to Reclamation in Utah" in an attempt to capture the very best methods which have been successful in that area. The guide provides excellent information on topics ranging from "shaping land" to "revegetating disturbance" relative to land uses including residential, livestock grazing, wildlife, conservation and restoration, industrial, and recreational. It does not provide any direct information relative to cultivated crop establishment or assessment.

The North Dakota Public Service Commission, Reclamation Division (2001) has developed "Standards for Evaluation of Revegetation Success and Recommended Procedures for Pre- and Post-Mining Vegetation Assessments". This policy document contains requirements and standards for evaluating revegetation success and recommended procedures for vegetation sampling and data analysis. This document provides requirements and approved standards for assessing revegetation success for bond releases. This document also provides recommended procedures for sampling, measurement, and statistical analysis of vegetation parameters.

Standards for cropland, tame pastureland, and native grassland are based on agricultural data sources, including reference areas on surrounding lands and published technical data. Data from reference areas can be used for direct comparisons with the reclaimed tract when all premining mapping units which existed in the tract area are represented by reference areas. A control area is similar to a reference area, as it contains one or more of the premining mapping units which formerly existed in the reclaimed tract.

Cropland is defined as land which is used for the production of adapted crops for harvest, alone or in rotation with grasses and legumes, and includes row crops, small grain crops, hay crops, nursery crops, orchard crops, and other specialty crops. Crops most commonly grown prior to mining must be used to measure productivity to determine reclamation success on areas being returned to cropland.

Normally, spring wheat (hard red spring wheat or durum wheat) must be grown for at least one of the years that measurements are taken on cropland for final bond release assessments. The reference area and the reclaimed tract must be planted at the same time and with the same crop species and variety in the years when yields will be compared.

Annual yield (bu/ac or lb/ac) is used to determine productivity of annual crops. Crop yields are obtained by harvesting the entire field or by a statistically valid sampling procedure. Where a sampling procedure is utilized the number of samples needed must be determined using a sample adequacy formula that reflects 90% statistical confidence.

For perennial crops (pasture, hay or native grass), the annual yield (lb/ac or t/ac) of the entire aboveground biomass is measured to determine productivity. Production of pasture, hay or native grasses may be assessed by determining annual peak standing yield or annual harvested yield. Perennial crop yields may be obtained from a whole field harvest or portions of a field can be sampled to obtain an estimated yield. Annual harvested yield may be obtained by haying the entire tract to obtain one yield value or by harvesting separate units to obtain an average bale weight.

Perennial grasses may also be hand harvested. Samples are clipped at ground level within a sampling quadrat. A single clipping per year of aboveground biomass may be made when dominant species are near peak production. The size and shape of the sampling quadrat used should be determined on the basis of the type of vegetation community to be clipped; however, consistent use of one size and shape is recommended. The number of samples for each sampling unit must be derived using a sample adequacy formula. If production data is to be used for assessing seasonality, clipped samples must be separated by growth forms including: 1) annuals, 2) perennial cool season grasses and sedges, 3) perennial warm season grasses, 4) forbs, and 5) shrubs and half-shrubs, and noxious weeds.

All clipped samples must be dried to a constant weight as soon as possible and weighed. Based on dry weights of the replicated samples, average production in lbs/ac must be calculated for each sampling unit.

Ground cover "means the area of ground covered by vegetation and the litter that is produced naturally on site, expressed as a percentage of the total area of measurement." Ground cover can be determined by basal or first-hit measurements. The type of cover measurement, whether basal or first-hit, must be consistent in pre-mine and post-mine measurements. The

measurement used must be specified and thereafter referred to as either basal or first-hit cover. Measurements for litter, rock, and bare soil must be included. Cover must be recorded by plant species. Measurement of cover near peak standing crop and prior to sampling for productivity is recommended.

In summary, the North Dakota approach involves relatively detailed vegetation assessment techniques in support of meeting their current regulatory requirements for revegetation. This requirement is to restore affected lands that have been designated for postmining agricultural purposes to the level of productivity equal to or greater than undisturbed or nonmined lands of similar soil types in the surrounding area, under equivalent management practices.

5. VEGETATION MEASUREMENT TECHNIQUES

The identification of an appropriate technique for assessing vegetation on reclaimed land first requires the identification of the appropriate characteristics to measure. This process must take into consideration the species characteristics such as growth form, community composition and plant distribution.

It is imperative that the assessor is familiar with and is able to identify all of the vegetation species that will be assessed. Different growth stages may make identification more difficult, especially with grasses, but it is necessary that accurate information be obtained.

This section will describe the vegetation characteristics that should be measured and the techniques that can be used to measure them. Means of setting up the study design and analyzing the data are also provided.

5.1 DEFINING THE VEGETATION ATTRIBUTES

It is important to know the differences between the vegetation attributes available for measurement. By knowing the differences, one can choose the most effective parameters to compare reclaimed land vegetation to control vegetation in different situations. Depending on the type of vegetation and the land use, it may be more important to monitor one attribute over another, for example, biomass of a forage crop. In researching the various vegetation attributes

available for measurement, only the most practical attributes were selected for use in the wellsite reclamation criteria based on vegetation types and appropriateness for monitoring.

One measure of vegetation growth is productivity. **Productivity** is defined as the vegetative yield produced by a unit area for a unit in time (Ries and Hofmann 1984). Productivity is sometimes confused with biomass or standing crop. Holecheck et al. (1998) states that biomass or standing crop have been used synonymously to refer to the weight of organisms at a given time. The difference between productivity and biomass is that productivity refers to yield produced over a specified time period, while biomass refers to yields at a particular point in time (Holecheck et al. 1998). The Bureau of Land Management (1999) defines these terms slightly differently. According to the BLM, gross primary production is the total amount of organic material produced, both above ground and below ground. Biomass is the total weight of living organisms (plants and animals) in the ecosystem. Standing crop is the amount of plant biomass present above ground at any given point, with peak standing crop being the greatest amount of plant biomass above ground present during a given year.

Biomass has been referred to as "one of the most important characteristics of range vegetation and may be the best single measure of growth" (Cook and Stubbendieck 1986). Since moisture content is variable, biomass is often expressed as an oven-dry weight. Bonham (1989) has also noted "vegetation composition, based on dry weight, is one of the best indicators of species importance within a plant community".

Throughout this document, biomass will be defined as the above ground vegetation yield at a given time. This includes standing vegetation and downed vegetation (alive and dead).

According to Van Dyne (1984) large losses in vegetation yield occur after maximum standing crop is reached. This is due to breakage of brittle leaves and stalks, to shedding of mature seed, to insect activity, or to translocation of food materials from leaves to crowns and roots. Knowing this, it becomes important to take time of year and crop maturity into consideration when doing biomass assessments.

Bonham (1989) states that biomass is an important parameter to measure because it indicates the quantity of resources, such as water, used by a species within the community. Biomass also measures how much of a community's resources are tied up within the different species.

Density has long been used to compare plant communities of similar life-form and size (Bureau of Land Management 1999). Density can be defined as the number of individual plants per area (Holechek et al. 1998), and is often expressed as numbers per square meter. In order to take accurate density measurements, it is necessary that individual plants be countable (Bonham 1989). This requirement makes density measurements questionable for small herbs and sod-forming grasses. Where the identity of individual plants may be difficult, or where individual plants are very small, this parameter may be too time consuming or inaccurate. Density cannot be converted to any kind of cover estimate (BLM 1999). Density measurements are repeatable over time because there is small observer error (BLM 1999). Quadrat size is important when determining density (Cook and Stubbendieck 1986). If the quadrat is too small, variation will be too high, while if the quadrat is too large, counting the plants will be too time consuming (Cook and Stubbendieck 1986).

Cover can be broken into five components: vegetation cover, foliar cover, canopy cover, basal cover, and ground cover. The criteria require the measurement of vegetation cover, which is the total cover of vegetation on the site (BLM 1999). Foliar cover is the area of ground covered by the vertical projection of the foliage (Holecheck et al. 1998). Small openings in the canopy and intraspecific overlap are excluded (BLM 1999). Canopy cover is the area of ground covered by the vertical projection of the outermost perimeter of the natural spread of the plants foliage. Small openings within the canopy are included; therefore, it is possible that the total canopy cover may exceed 100% (BLM 1999). Figure 2 shows the difference between foliar cover (on the left) and canopy cover (on the right). Basal cover "refers to the area occupied at the intersection of the plant and soil surface" (Holecheck et al. 1998). Ground cover is the cover of plants, litter, rocks and gravel on the site (BLM 1999). Cover can be estimated as a direct percentage, or it can fit within pre-determined cover classes.

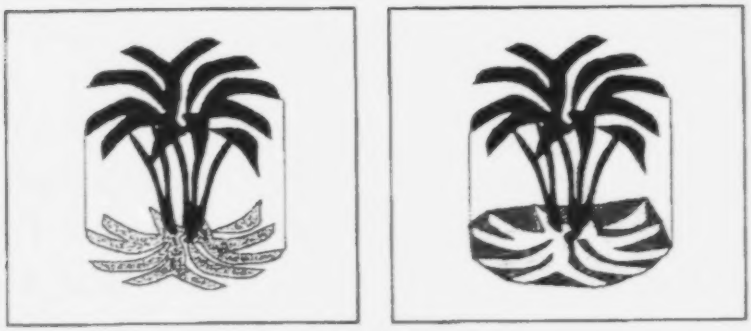

Figure 2. The difference between foliar cover (on the left) and canopy cover (on the right).

Figure taken from Bureau of Land Management. 1999. Sampling Vegetation Attributes. Interagency Technical Reference, Cooperative Extension Service. BLM/RS/ST-96/002+1730. U.S.D.A. Forest Service and U.S. Dept. of the Interior.

Canopy cover and foliar cover are the most sensitive to climatic and biotic factors, which can often lead to errors in interpretation. In mixed communities where canopy cover by species is required, overlapping canopy covers often create problems with measurements as well (BLM 1999). Basal cover is important because it does not vary as widely from year to year as canopy cover, but it is often more difficult to measure, particularly in sod-forming grasslands (Van Dyne 1984).

Cover is most often measured using plot frames (quadrats), points or lines. These methods will be discussed further in this section. Plotless techniques have been used in the past, but they are difficult to use when cover is greater than 35% (Bonham 1989).

Species Composition is a value calculated by comparing an individual value (such as weight, density, or percent cover) for one species to the total value of the entire population (BLM 1999). The method used for obtaining the values used in the comparison varies according to the values measured. As mentioned previously, certain measurements are more sensitive to climatic influences than others, and hence the repeatability of the composition calculation depends on the values measured.

Plant vigor is often used as an indication of ecosystem **health**. Criteria used to evaluate plant vigor can include height of leaves, length of twigs, number of flower stalks, and amounts of seed produced (Van Dyne 1984). Using the basic properties of the vegetation, one can also

determine the height per plant, area per plant, biomass per plant, and biomass per unit cover per plant species (Van Dyne 1984). Measurements of the heights and diameters of individual plants are often used in studying grazed lands (Van Dyne 1984). The plants are selected at random and generally the longest leaf or the tallest seed stalk is measured. Diameter of the plant is taken at ground level, which can be more accurately obtained by determining a minimum and maximum value for the stalk due to the irregularity of the stalks' growth (they are not always circular) (Van Dyne 1984).

Many studies support the idea that plant height, number of flower stalks, and amounts of seed produced are the most commonly used and most easily measured criteria for determining plant vigor (Cook and Stubbendieck 1986). If plant height is used as a measure of plant vigor, it is a relative measurement that can only be used for assessments at one point in time over areas with similar characteristics (Cook and Stubbendieck 1986).

Cook and Stubbendieck (1986) suggest that plant vigor can be indicated by these physical characteristics: 1) size and appearance of plants – plants with poor vigor may have dead centers, decadent appearance, or dead branches, 2) height and number of stems, 3) number and size of fruiting bodies or seed heads, 4) size or area of foliage, 5) date of renewal of spring growth and rate of foliage development, 6) herbage production, 7) color of foliage has also been suggested, and 8) root production. The physiological and root characteristics that may indicate plant vigor include "1) manufacture and storage of plant food reserves, 2) amount and characteristics of chlorophyll, and 3) winter and drought hardiness".

In essence, all of the factors that affect plant vigor are integrated into biomass production (Cook and Stubbendieck 1986). Therefore, biomass measurements are a more accurate and thorough measure of plant vigor. All comparisons of vigor and/or biomass should be made within treatments of the same age and at the same time of year. Yearly comparisons can only be compared if samples were obtained at the same phenological stage i.e. at peak production (Cook and Stubbendieck 1986).

The following vegetation attributes were researched and considered, but based on the goals of the criteria, it is not necessary to measure these parameters.

Frequency is a quantitative expression of the proportion of sample units that contain a given species. This vegetation parameter is not useful to measure as a comparison of wellsite reclamation and control areas because in many cases the areas are seeded to the same species.

Abundance is a visual estimation of the number of individuals of each species within an area, based on a class structure (Randall 1978). Again, this vegetation attribute is somewhat unnecessary to look at, as the areas are often seeded with the same single species or the same mixture.

Structure of a vegetation community looks at the three-dimensional arrangement of the foliage. The primary value of structural diversity is for providing wildlife habitat. Vegetation is measured in layers on vertical plains by estimating the cover of each layer or by measuring the height of the vegetation. Although wildlife habitat is an important feature to develop, the criteria does not focus on assessing the availability of wildlife habitat within reclaimed areas.

5.2 DEFINING THE METHODS OF MEASUREMENT

Photographs and video recordings are beneficial in documenting the change of a landscape, or to document trouble spots within a community. In some cases it is best to photograph a permanently marked photo point, so that continuous photos can be taken year after year in the same location to monitor changes over time. In many situations though, this is not an option due to land use, i.e. a farmer's field. All pictures taken should be in color, and there should be a device used for scale within the picture ie. a shovel, soil knife, or measuring tape. Ensure detailed field notes are taken to document the date and time the photos were taken, along with the detailed location information and aspect of the picture. It may also be beneficial to write the information on a card and place the card within the area to be photographed so that it is readable in the picture. General overviews of the area, as well as detailed close-ups of problems such as vegetation impacted by disease or insects, weather damage, bare spots on the ground, excessive stoniness, erosion, etc. are excellent opportunities for photo documentation.

All methods used to measure vegetation characteristics have their advantages and disadvantages. It is the goal of this section to provide an overview, or a general understanding of some of these methods, along with the pros and cons of using each. The purpose is not to outline every single method used, but to provide an example of some of the methods that can be used or are recommended for use in conducting site assessments.

The use of a method is very dependent upon the type of information that is to be gathered, the type of vegetation that is to be measured, the structure of the community, along with the parameters chosen within the method. For example, when using a quadrat-based

method to measure cover, a rectangular-shaped sampling unit will cause more variation to occur between units than within a unit (Bonham 1989).

It has been recommended that measurements of density, height, diameter, frequency, and vigor be made at or near the time of peak standing crop; the phenological stage of the plant community at the time of cover measurements is not as important (Van Dyne 1984).

5.2.1 Daubenmire

The Daubenmire method is used to monitor canopy cover, frequency, and composition by canopy cover (BLM 1999). It is a widely accepted and well-used method, and is well suited to a variety of vegetation types as long as the plants do not exceed waist height (BLM 1999). If time is not available for estimating biomass (g^2/m), cover may be the next best parameter to estimate (Knight 1978). The Daubenmire method is relatively simple and quick to use. A limitation to measuring canopy cover is that there can be large changes in it between years due to climatic conditions (BLM 1999).

For the Daubenmire method it is necessary to have a quadrat frame made of about 3/16 – 3/8 inch iron/steel rods, with inside dimensions of 20 x 50 cm (Figure 3). The frame should also have 2-4 cm legs welded to each corner to hold the frame in place during measurements (BLM 1999; Knight 1978). It helps during the measurements if the frame is painted with alternate colors of red and white or orange and white to indicate quarter sections. In one corner, mark on the two sides of the frame a 71 mm square. This area represents 5% of the quadrat (BLM 1999; Knight 1978). The painted design provides visual reference to sections 5, 25, 50, 75, 95, and 100% of the size of the plot area (BLM 1999).

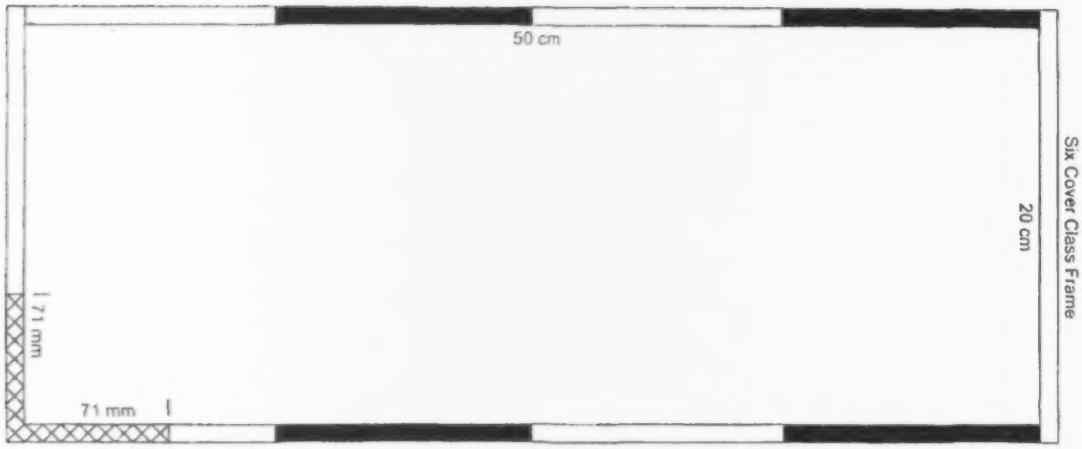

Figure 3. The Daubenmire Six Cover Class Frame.

Figure taken from Bureau of Land Management. 1999. Sampling Vegetation Attributes. Interagency Technical Reference, Cooperative Extension Service. BLM/RS/ST-96/002+1730. U.S.D.A. Forest Service and U.S. Dept. of the Interior.

Prior to implementation, decide whether or not to include plants that are not rooted in the frame but whose canopy is extending over the frame. This needs to be consistent throughout the measurements. Use a study layout such as the baseline, macroplot, or linear study design. The linear technique is the most often used (BLM 1999). Place the quadrat frame along the tape at specified intervals and estimate the canopy coverage of each plant species. Look from directly above the frame and consider all individuals of a species within the frame as one unit. Imagine vertical lines dropping down from the leaf tips to the ground, projecting canopy cover. Determine which class this percent of canopy cover falls into according to Daubenmire's table (Table 2). Overlapping canopy cover is included in the cover estimates; therefore, total cover may exceed 100 percent. It is also beneficial to perform these measurements at the time of maximum growth of the key species (BLM 1999).

Table 2. Daubenmire cover classes used in estimating vegetation cover.

Coverage Class	Range of Coverage	Midpoint of Range
1	0-5%	2.5%
2	5-25%	15.0%
3	25-50%	37.5%
4	50-75%	62.5%
5	75-95%	85.0%
6	95-100%	97.5%

To calculate canopy cover, add together all of the corresponding mid-range values and divide the number by the number of plots examined. Divide the number of quadrats in which the species occurs by the total number of quadrats sampled, and multiply that value by 100 (BLM 1999). Species composition is determined by dividing the percent canopy cover of each plant species by the total percent canopy cover of all plant species (this value can be greater than 100) (BLM 1999).

Another alternative to using the coverage class system is simply to estimate percent cover visually. The advantage of using the coverage class values is less sampling time, and greater repeatability (BLM 1999).

Bonham (1989) describes another similar method to determine cover called the Area-List Method. A list of all the species in the area is required. Foliage or basal area cover of each species within the plot is then determined to the nearest 1%, usually through visual estimation. This method is best suited to species that form well-defined clump, bunches, tufts, or tussocks (Bonham 1989). Quadrats 0.5 m^2 (0.5 x 1.0 m) are most often used.

The Daubenmire frame (or equivalent in size) is recommended for use in determining height, density, and yield potential of cultivated crops.

5.2.2 Density

For species where identification of individual plants is difficult, density can also mean the number of stems, inflorescences, culm groups, or other plant parts per unit area instead of the actual number of individuals per unit area (BLM 1999). This method is widely used with grasses, forbs, shrubs and trees. Density is an absolute measurement and is often quick and easy (BLM 1999). It can also be more difficult in dense populations and when sod-forming plants or

multi-stemmed grasses are involved. Prior to implementation of the sampling, it is necessary to determine a course of action for when these situations arise. Due to the variations in the quadrat size requirements of different species, sampling is often limited to one or a few key species at a time (BLM 1999).

Bonham (1989) notes that density is most often measured from plots. He notes that the equipment necessary to measure density is rather simple and observer training is not extremely time consuming. Plots with boundaries of 1, 4, and 10 m sides form 1, 16, and 100 m^2 areas respectively. Often these are used as nested quadrats with the 1 m^2 placed in the corner of the 16 m^2 plot and the latter placed in the corner of the 100 m^2 plot (Figure 4). Herbaceous plants are counted in the 1 m^2 plot, shrubs are counted in the 16 m^2 plot, and trees in the 100 m^2 plot (Bonham 1989).

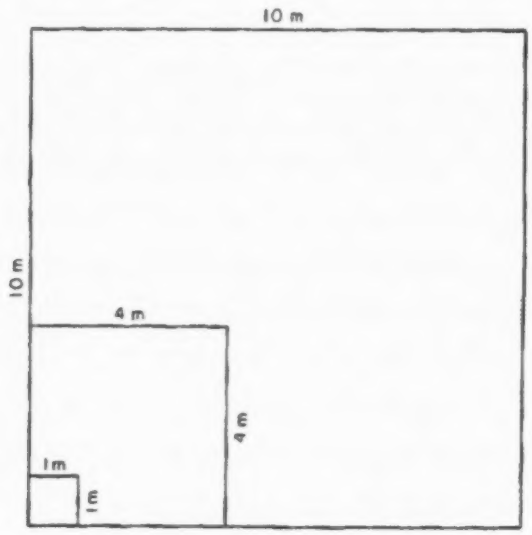

Figure 4. Nested plots used to measure density

Figure taken from Bureau of Land Management. 1999. Sampling Vegetation Attributes. Interagency Technical Reference, Cooperative Extension Service. BLM/RS/ST-96/002+1730. U.S.D.A. Forest Service and U.S. Dept. of the Interior.

Conversely, the Bureau of Land Management (1999) suggests that long, thin quadrats are better than circles, squares, or shorter and wider quadrats. The narrower the quadrat, the more edge effect there is, but this can be overcome by incorporating rules for determining whether a plant falls inside or outside a quadrat (BLM 1999).

The Bureau of Land Management (1999) suggests using the macroplot layout that uses an x- y- axis system along with tape measures and meter sticks. In their example they use quadrats of 1 m x 16 m size and place their long sides parallel to the x-axis. The number of individuals (or other unit) of the key species is counted and recorded. Only the plants that are rooted in the quadrat are counted. Previous to implementation of the sampling procedure, rules are set for determining whether or not a plant is considered inside or outside the quadrat. This will minimize the edge effect. The Bureau of Land Management (1999) suggests counting those individuals that fall on the left and top edges of the quadrat as being inside and those that fall on the right and bottom edges of the quadrat as being outside the quadrat. All observers must follow the same set of rules.

Average density per quadrat is calculated by dividing the total number of plants counted in the sample by the number of quadrats in the sample (BLM 1999). If more than one species was assessed, perform this calculation for each species individually. The total density of the macroplot can be calculated by multiplying the average density per quadrat by the total number of possible quadrats in the macroplot. Again, this calculation is done by individual species. For example, if there are 200 possible quadrats in a macroplot, and the average density per quadrat is 4.4 (ie. 177 plants were found in 40 quadrats), then 4.4 plants/quadrat x 200 quadrats = an estimated 880 plants in the macroplot (BLM 1999).

5.2.3 Harvest

Bonham (1989) suggests that the best and perhaps the most commonly used method to measure herbaceous production is to clip or harvest total standing biomass. The general purpose of the harvest method is to determine the amount of above ground vegetation production in the current year. The peak standing crop and species composition by weight can be determined with this method (BLM 1999). This technique is best suited to grasslands and desert shrublands.

Simplified biomass measurements can be obtained by clipping (harvesting) at ground level all plant material that is alive. Separate into bags by species. The dead material on the ground may also be collected, but keep it separate from the live plant material. The Bureau of Land Management (1999) recommends including all parts of the plants within the quadrat only; do not include parts of the plant that lay outside the vertical projection of the quadrat, even if the plant is rooted within the quadrat. Knight (1978) recommends drying the collected material as

soon as possible at 50 degrees centigrade, then weighing and recording the weights once the vegetation is completely dry. The Bureau of Land Management (1999) recommends drying the samples at 60 degrees centigrade for 24 hours before weighing to determine air-dry weight. Ensure that the bags are marked with the date, transect number, quadrat number, and species (BLM 1999).

Bonham (1989) notes that there have been a lot of studies on the size and shape of quadrats used in clipping plots. Certain sizes of rectangular and circular plots are quicker to use, while some are more statistically efficient. There are ultimately optimum plot sizes and shapes for determining biomass of forbs, grasses, dead material and total green material. In general, dense herbaceous vegetation makes small plot areas more efficient, while sparse vegetation is better suited to large plot areas. The most commonly used size is 0.5 m^2, whether it is rectangular (1 m x 0.5 m), square (0.71 m x 0.71 m) or circular (radius of 0.399 m).

The green weight and dry weight for each species are totaled for each transect. Percent composition is determined by dividing the total dry weight of each species by the composition totals.

According to Bonham (1989), measurements of cover and frequency can be used to estimate the biomass production of some species with correlation coefficients of 90% and more. Generally, these results fail to be unbiased due to improper statistical procedures.

The Reclamation Division of the North Dakota Public Service Commission (2001) has broken down their recommendations for harvest sampling by crop type. They recommend that annual crops be sampled by harvesting the entire field to retrieve weight/yield of biomass; by combine sampling to retrieve weight/yield of the harvest strips which are statistically laid out; by hand sampling which will most likely provide significantly higher yields than other methods; or by harvesting representative strips throughout the area (North Dakota Public Service Commission 2001).

The Reclamation Division of the North Dakota Public Service Commission (2001) recommends that perennial crops can be sampled through an entire field harvest to retrieve weight/yield of the biomass. To do this, random bales can be weighed to determine average bale weight, which can then be used to calculate the total biomass harvested based on the number of bales over the field. Strips can be harvested and random bale weights used to determine yield in the same process as above, but relative to the size of the strips harvested. Also, the Reclamation

Division of the North Dakota Public Service Commission (2001) recommends perennial grasses may be hand harvested within quadrats. This should take place when species are near peak production (North Dakota Public Service Commission 2001).

The technique of harvesting forage crops to determine biomass in 0.5 m^2 quadrats is recommended.

5.2.4 Photo Monitoring

Photographs and video recordings are beneficial in documenting the change of a landscape, or to document trouble spots within a community. In some cases it is best to photograph a permanently marked photo point, so that continuous photos can be taken year after year in the same location to monitor changes over time. In many situations though, this is not an option to due land use. For example, permanent plot stakes cannot be located within a field that is harvested annually. General overview photos of an area are less likely to require permanent photo plots than are close-up photos. The Bureau of Land Management (1999) recommends general overview photos of the area because they are beneficial when relocating study sites. Photographic monitoring is a subjective visual assessment.

All pictures taken should be in color, and for close-ups photos there should be a device used for scale ie. a shovel, soil knife, or measuring tape. For taller vegetation, a graduated stake or a well-marked measuring stick can be stood up within the picture to allow for vegetation height comparison between each visit and location. Ensure detailed field notes are taken to document the date and time the photos were taken, along with the detailed location information and aspect of the picture. It may also be beneficial to write the information on a card and place the card within the area to be photographed so that it is readable in the picture. General overviews of the area, as well as detailed close-ups of problems such as vegetation impacted by disease or insects, weather damage, bare spots on the ground, excessive stoniness, erosion, etc. should be taken.

A protocol for obtaining photographs pertinent to conducting pre-construction site assessments and detailed site assessments is defined in the criteria.

5.2.4.1 Photoplots. Elzinga et al. (1998) from the Bureau of Land Management, state that photoplot monitoring involves using a frame to delineate a small area (plot) on the ground. The

photograph is often taken from a specified height above the ground, so that the plot area fills most of the photograph frame. It is noted that photoplots are sometimes used to evaluate weedy species invasion, successional changes, soil disturbance and trampling (Elzinga et al. 1998).

The Bureau of Land Management (1999) recommends using 1 m x 1 m plots. Frames can be made of any material, but are most often made of PVC pipe or steel rods. An identification label should be placed within the picture area. Again, the photographer should stand on the north side of the plot, with the toes touching the frame edge, bending over the center of the plot. If the plot is larger than 3 ft x 3 ft, the BLM (1999) recommends using a small footstool to take the closeup photos of the plots.

In Elzinga et al. (1998) they describe a frame constructed of PVC that suspends a camera with a 28 mm lens 1.4 m above the ground. The camera frame is attached to a 1 m x 1 m gridded frame that rests on the ground. By using a cable release run from the camera, the photographer does not have to trample the ground cover when taking the photo.

Elzinga et al. (1998) suggest that if time is very limited during field season, and individual plants can be identified within the plot on the photo, photoplots can be used to measure density away from the field. Due to obvious sources of problems such as inability to identify species, species hidden beneath the leaves of other species, and an overall increase in time to do the job, this technique is not suggested.

It is also suggested that the photoplot pictures can be used as sampling units for cover (Elzinga et al. 1998). A dot grid can be placed over the photo and cover can be calculated by determining the number of "hits" per species. This is not effective for small, hidden species. Another way to determine cover is to define polygons around the canopy by species. Using a planimeter, the area of the polygons by species provides an estimate of canopy cover (Elzinga et al. 1998). This method may pose errors in determining the polygon boundaries, due to difficulties in delineation, as well as inconsistencies in judgment between observers. The scale of the photograph can also cause errors in determining cover (Elzinga et al. 1998). If possible, the scale used in photographing the plots should be kept consistent.

5.2.4.2. Photopoints. Photopoint monitoring uses a fixed location such as a landscape marker that is used year after year to shoot photographs of the same view (Elzinga et al. 1998). This is useful for comparing the ecological change of one location over time. GPS technology is useful

for documenting exact locations of photopoints where it is not practical to place a permanent stake in the ground, or where landscape features aren't dominant. The Bureau of Land Management (1999) notes that these kinds of photos are often adequate to visually portray dominant landscape vegetation. They recommend detailed information be maintained about the location of the photopoint, that a distinct marker such as a fence or landmark is included in the photo, and that previous photos of the site be taken into the field to aid in finding the same location again.

5.2.4.3. Aerial Photography and Remote Sensing. Remote sensing has a vague definition, but can be described as "a range of techniques which involve the collection of spectral data from a platform that does not touch the object of interest. ...from taking a photoplot with a camera suspended from a hot air balloon to satellite-based imagery" (Elzinga et al. 1998). Elzinga et al. (1998) state "in general, the resolution of satellite imagery does not lend itself to the site-specific plant population monitoring situations..." that this document is focuses on.

Aerial photos can be collected using a fixed-wing aircraft or a helicopter. Aerial photography using infra-red film has often been used to map vegetation communities over large areas. Large-scale (1:200) color or infra-red photos have been used to map plant species, provide plant cover estimates, and determine soil surface condition (Fidelibus and Mac Aller 1993). Neither type of film provides definitive results as there may be some species that are too small to be seen on film, or some species may be obscured by other foliage or shadows. Also, aerial photos should be taken within 4 to 6 weeks of effective rainfall (Fidelibus and Mac Aller 1993). This along with the expense of setting up a permanent flight line, and acquiring and printing the photos, it's not very cost effective. In the past, helium balloons have been used as a less expensive method of gathering aerial photos and videotape, but there are obvious difficulties in this process, most of all is wind (Fidelibus and Mac Aller 1993).

Most photo series are taken in stereo-pairs (Elzinga et al. 1998). Using a stereoscope, these photos can be viewed in 3-D. This is often beneficial for identifying features that are not as easily identifiable at ground level. It may also be possible to compare an older series of aerial photos to a newer series to identify changes in the vegetation population.

Aerial videography involves the use of video cameras and low-level fixed-wing aircrafts (Elzinga et al. 1998). The spectral data collected by the video cameras can be used for mapping

and monitoring plant communities (Elzinga et al. 1998). The better the quality, the more expensive the equipment.

5.2.5 Statistical Considerations

It is important that good professional judgment is maintained throughout all of the sampling procedures. If study areas are set up in a statistically valid manner, it is difficult, though convenient, to make inferences regarding the larger areas that they are chosen to represent. In a truly subjective setup, a sample population cannot truly represent a larger population (BLM 1999). It is also important to base management decisions on each study site independently. Data from different sampling sites should never be averaged (BLM 1999).

Random sampling is necessary to ensure appropriate statistical analyses can be performed on the data collected. Without randomized sampling techniques it is impossible to determine the probability of selecting a particular sampling unit, and hence no statistical inferences can be made on the population (BLM 1999).

6. RANGE HEALTH ASSESSMENT

Range health assessments provide a basic understanding about the plant communities and soils in areas of rangeland, which include grassland, grazeable forestland, shrubland, pastureland, and riparian areas. Rangeland is defined as land supporting indigenous or introduced vegetation that is either grazed or has the potential to be grazed and is managed as a natural ecosystem (Adams et al. 2003).

The following discussion regarding the background information and rationale for using a range health assessment is extracted from Adams et al. (2003).

Range health means the ability of rangeland to perform certain key functions. These functions and a description of their importance are provided in Table 3.

Table 3. Important rangeland functions.

Rangeland Functions	Importance
Productivity	• Healthy range plant communities are very efficient in utilizing available energy and water resources in the production of maximum biomass • Forage production for livestock and wildlife • Consumable products for all life forms (e.g., insects, decomposers, etc.)
Site Stability	• Maintain the potential productivity of rangelands • Protect soils that have taken centuries to develop • Supports stable long-term biomass production
Capture and Beneficial Release of Water	• Storage, retention and slow release of water • More moisture available for plant growth and other organisms • Less runoff and potential for soil erosion • More stable ecosystem during drought
Nutrient Cycling	• Conservation and recycling of nutrients available for plant growth • Rangelands are thrifty systems not requiring the input of fertilizer
Plant Species Diversity	• Maintains a diversity of grasses, forbs, shrubs and trees • Supports high quality forage plants for livestock and wildlife • Maintains biodiversity, the complex web of life

Healthy rangelands can sustain a broad range of values and benefits as described in Table 4.

Table 4. The values and benefits of healthy range to various rangeland users.

Rangeland Users	Values and Benefits of Healthy Range
Livestock Producers	• Lower feed costs • Renewable and reliable source of forage production • Stability of forage production during drought • Greater flexibility and efficiency for alternate grazing seasons (e.g., autumn or winter where applicable) • Lower maintenance costs like weed control • Does not require the input of inorganic fertilizers and other soil amendments and additives • Reduced concern for noxious weeds
Resource Managers	• Quality wildlife habitat • Maintain fisheries habitat • Maintain grazing opportunities • Preventing soil erosion • Timber production • Increased total net benefits
The Public	• Esthetic landscape values • Watershed protection • Water quality • Large soil carbon sinks • Biodiversity • Opportunities for passive and consumptive recreation like hunting and tourism
Socio-Economics and Governance	• Healthy rangelands provide increased cooperation, increased total benefits to society with fewer conflicts to resolve, less regulation and enforcement. This means lower costs!

6.1 INDICATORS OF RANGE HEALTH

6.1.1 Integrity and Ecological Status

Plant species composition is a fundamental consideration in range health assessment. Plant species composition influences a sites ability to perform functions and provide products and services. Native plant communities evolve within their environment and slowly change over time as environmental factors change. Significant short term changes in plant composition do not normally occur unless caused by significant disturbances like continuous heavy grazing, high levels of recreational traffic, prolonged drought, prolonged periods of high precipitation, exotic species invasion, frequent burning or timber removal.

Range management objectives tend to favor the later stages of plant succession (late-seral to potential natural community (PNC) or good to excellent range condition). Late seral plant communities tend to be superior in the efficient capture of solar energy, in cycling of organic matter and nutrients, in retaining moisture, in supporting wildlife habitat values and in providing the highest potential productivity for the site. In contrast, early seral stages represent plant communities with diminished ecological processes, which are less stable and more vulnerable to invasion by weeds and non-native species. They also have diminished resource values for livestock forage production, wildlife habitat and watershed protection.

Modified plant communities are communities that have become dominated by non-native species.

6.1.2 Community Structure

Nutrient cycling and energy flow is more efficient in diverse plant communities with varied canopy structures and rooting depths that can use sunlight, water and nutrients from different zones in the canopy and soil. Plant community structure is particularly important in maintaining net primary production in forested rangelands, and in the maintenance of habitat values for a spectrum of species including browsing opportunities for ungulates, and feeding and nesting sites for breeding birds.

6.1.3 Hydrologic Function and Nutrient Cycling

This indicator deals with abundance and distribution of live and dead plant material on an ecological site. Plant residue promotes moisture retention and nutrient cycling and is linked to another indicator, site stability (soil exposure and erosion). When functioning properly, a watershed captures, stores and beneficially releases the moisture associated with normal precipitation events. Uplands make up the largest part of the watershed and are where most of the moisture is captured and stored during precipitation events. Live plant material and litter (either standing, freshly fallen or slightly decomposed on the soil surface) is important for infiltration (slowing runoff and creating a path into the soil), reducing soil erosion from wind and water, reducing evaporative losses and reducing raindrop impact.

6.1.4 Site Stability

Rangelands show varying degrees of natural soil stability depending on climate, site, topography, and plant cover. The amount of sediment produced by water and wind erosion from a particular ecological site type is termed geologic erosion. Managers strive to prevent accelerated erosion due to land management practices by maintaining adequate vegetation cover and minimizing exposed soil. Adequate vegetation cover protects the soil surface from the impact of raindrops, detains overland flow, maintains infiltration and permeability and protects the soil surface from erosion. Soil loss is a serious concern since erosion tends to remove the finer, lighter particles like clays, silts and organic matter which are most important to soil fertility and moisture holding capacity.

6.1.5 Noxious Weeds

Noxious weeds are invasive plants that are alien species to the rangeland plant community. Weeds are seldom a problem in vigorous, well managed rangelands although weed invasion may occasionally happen in healthy stands. Weeds may be introduced to relatively healthy stands through rodent burrows, but generally their presence indicates a degrading plant community. Weeds most often invade range where grazing practices have resulted in available niche space (bare soil, surplus moisture); available micro-habitats normally occupied by range plants, but now available to weeds due to overgrazing or some other land use or natural disturbance. Noxious weeds diminish the agricultural productivity of a site, threaten biological diversity, reduce structure and function and sustainability of ecosystems. They also reduce the multiple uses and values that range is normally capable of providing.

6.2 ASSESSMENT METHODOLOGY

The field workbook prepared by Adams et al. (2003) outlines the new range and tame pasture health assessment methodology. Field worksheets for grassland, forest, and tame pasture are provided.

7. SOIL AND VEGETATION VARIABILITY

Variability is part of a natural ecosystem. It is found within landscape attributes and vegetation communities. Variability may include differences in slope or drainage across a field, or the variation in vegetation size and yield. The Reclamation Assessment Criteria for Pipelines Draft (Alberta Environment 2001) notes that grain yields can show a range of 50% or greater across a field, and that topsoil depth in the Black Soil Zone can range from 5 to >40 cm, with individual fields ranging up to 9 cm around a 16 cm average.

The concept of variability in relation to reclamation involves understanding and identifying the acceptable ranges of variability within a landscape. This might include the identification of a minimum, maximum and an average condition found in a natural environment (Alberta Environment, 2001).

Miao et al. (2000) compared the soil spatial variability in crop and rangeland in Texas. The study examined the spatial variability of pH, electrical conductivity, soil organic carbon at three depths (0-5 cm, 5-15 cm, and 15-25 cm), and soil water content at 0-15 cm in 200 m x 350 m plots on adjacent cropland and rangeland. Miao et al. (2000) found that "cropland displayed higher variability of pH and EC at 0-5 cm, and higher variability of water content at both times of sampling. Rangeland displayed higher variability of soil organic carbon at all three depths than cropland. Generally, most soil properties on cropland had stronger spatial dependence than on rangeland…". Miao et al. (2000) note that due to the lack of spatial dependence on rangeland soils, it would be "more difficult to design an optimal soil sampling plan to capture the soil variability. It may also be difficult to use soil spatial variability information to aid in applying site-specific management strategies on rangeland."

In a Virginia, US study by VanDyke et al. (1999) it was determined that ignoring within-farm variability may result in overstating the farm's costs of reducing nitrogen losses. The study noticed that manure applications could cause nitrogen losses through runoff and leaching due to factors such as uncertain nitrogen mineralization. Hence, nitrogen control costs can be reduced by applying manure only to soils with less nitrogen loss potential. Identification of soil variability may play an important role in running a cost-effective farm.

In Corvallis, Oregon some vineyards use precision soil mapping to effectively monitor the soil variability, ensuring high quality wine grapes (Gallagher 2001). This entails soil sampling to determine drainage class, available water holding capacity, depth to rock and root

restrictions. More details are collected in areas with varying parent materials, textures and potential vigor. The soil information is collected using a global positioning system (GPS) and is presented using geographic information system (GIS) thematic soil maps. The information obtained regarding various soil parameters is used to develop vineyard design, nutrient sampling scheme, irrigation plans, cover crop planting, fertilization, etc. (Gallagher 2001).

Alberta Agriculture, Food and Rural Development (1998) provides a fact sheet relative to precision farming, which they define as the "site-specific management of farm fields." They also provide a definition for toposequence variability – a very common "systematic or recurring variability along a slope from crest to depression". The magnitude of the variability is relative to the scale of the land, which is a function of the landform (Alberta Agriculture, Food and Rural Development 1998).

According to Alberta Agriculture, Food and Rural Development (1998) there is a benchmark site at Provost, in east-central Alberta that provides researchers with an opportunity to study soil variability across relatively short toposequences across a wide variety of morainal landscape. The cultivated land component was established in 1990, and the uncultivated, or native component was established in 1991. Both sites have been monitored using the same methods. The average toposequence length at the cultivated site was 65 m long, and 80 m long at the native site. Topsoil pH, organic C, total N, and plant-available K were only some of the parameters analysed.

Major findings at the Provost sites include the following: higher pH levels on cultivated hilltops versus lower slopes and depressions, and native land; lowest levels of organic C and total N on cultivated hilltops versus lower slopes and depressions possibly due to admixing and erosion on the hilltop positions; lower C:N ratios on hilltops versus backslopes and footslopes, possibly due to lower return of plant residues caused by erosion; lower plant available K levels across cultivated hilltops possibly due to admixing and erosion; and highest levels of plant available K occurring in cultivated depressions, where the deposition of plant residues and soils from surrounding slopes has gathered (Alberta Agriculture, Food and Rural Development 1998). Major concerns relative to the variability of soil characteristics can include the following: interactions of pH and carbonates with nutrients such as P can be detrimental to crop growth; pH alone can be detrimental to crop growth; pH can affect herbicide management on cultivated land (some degrade slowly at high pH's and can leave residues that are harmful, some are more

mobile at high pH's, some are less degradable at lower pH's, etc.); moisture changes from year to year and throughout the year can affect a wide variety of soil parameters; and the availability, cost and effectiveness of amendments to control soil erosion and organic matter loss can be worked into the equation (Alberta Agriculture, Food and Rural Development 1998).

The Potash and Phosphate Institute (2000) notes that both phosphorus and potassium move in the soil principally by diffusion, which is influenced by soil moisture and soil temperature. Soil nutrient levels vary throughout a field due to landscape, erosion, and past management variability. Nutrients such as nitrate, sulfate and chloride are more mobile than others and move with water to accumulate in lower slope positions, while immobile nutrients such as phosphorus and potassium bind to soil and movement is most often a result of soil erosion or tillage.

The Potash and Phosphate Institute (2000) recommends using more than one soil sample to determine nutrient levels. When only one sample is possible, it is necessary to sample within the area that best represents average productivity. It is more effective to sample in a variety of differing regions of productivity to ensure more accurate fertilizer application for each area.

Brook (1998) provides some information regarding crop variability and describes an instrument used to monitor grain yield. The basic components of this type of equipment are the grain flow sensor, grain moisture sensor, ground speed sensor, and the processing and display module. There is also note of methods used to map the yields of non-grain crops such as potatoes and tomatoes that use GPS.

Brook (1998) also makes mention of soil variability. In the past, soil samples were collected randomly throughout a field, the conditions were averaged, and the entire field was treated based on that average. With precision agriculture it is possible to treat any portion of the land based on its needs and requirements. The land can be mapped using grid sampling to ensure an unbiased, simple and quick method to determine soil variability. Grid sampling uses high density soil core sampling to reveal soil fertility patterns. Considerations for using grid sampling include: the resulting averages between grid cells; the lack of consensus on grid size; the effect of systematic errors and localized irregularities; and the possibility for under and over sampling of soil regions. Steps to improve the quality of grid sampling can include: using an unaligned sample design to minimize systematic errors; increase the sample radius; and adjust grid sampling intensity based on available variability information (Brook 1998).

Brook (1998) also recommends using directed sampling to determine soil variability within a farmers' field. This type of sampling is based on farmer knowledge and experience, historic soil maps, previous yield and grid sample maps, topography maps, aerial images, and historical management information. This type of variability sampling avoids problems often encountered with grids, and may provide a more practical way to delineate the size and shape of regional variability (Brook 1998). Directed sampling may be more cost effective than an intense grid sampling system, but it is only practical if qualified personnel are available to collect the information and make the final decisions.

8. TRAINING

All of the stakeholders provided comments regarding the need for training related to all aspects of construction and reclamation of a site. In the pre-construction phase, training would assist staff in the siting process and adjustment of the location where possible, if potential landscape or soil problems have been identified.

Many stakeholders commented on the need for training for equipment operators involved in the salvage and replacement of soils. This is the most critical aspect in ultimately achieving reclamation success.

Much was said about the employment of qualified soil scientists both from the industry/consulting perspective and the regulatory perspective. While stakeholders indicated that some staff currently in the business had limited knowledge of soils they indicated specific areas of concern. These included:

- Lack of understanding of soil classification and recognition of basic soil morphological features such as structure. Specific concerns were raised regarding Solonetzic and Luvisolic soils.
- Poor understanding of soil variability.
- Difficulty in determining what is representative when selecting assessment locations in the grids and selection of controls.
- Need to improve basic skills including soil texturing.

Although not directly related to training, several individuals commented on the need for more consistency of interpretation between inspectors in different areas of the province.

9. PERFORMANCE MONITORING

Monitoring the performance of selected sites constructed and reclaimed using the parameters and criteria outlined would be useful in determining the level of reclamation success achieved in the longer term and the overall effectiveness of the criteria. Three major areas would be evaluated:

1. The effectiveness of conducting pre-construction site assessments in improving site construction and reclamation practices
2. Soil quality and soil performance
3. Vegetation performance

The discussion will emphasize soil and vegetation performance.

9.1 SOIL PERFORMANCE

Topsoil replacement depth and topsoil quality represent the two most critical areas relative to soil handling associated with wellsite construction and reclamation. Because of the limited amount of research done related to wellsite reclamation, the review of the literature relative to soil replacement depth included research more related to soil erosion impacts. In these studies soil losses were evaluated in increments of 5 or 10 cm. In reality work should be undertaken that would involve smaller increments of 1 to 2 cm to provide some relevant data.

Ideally, in order to get a good understanding of the "effectiveness" of the recommended criteria, monitoring should be undertaken at sites associated with different land uses and soil types. For example, one site could be selected in each of the major soil zones including Brown Chernozem, Dark Brown Chernozem, Black Chernozem, Gray Luvisol, and Solonetzic associated with the cultivated land use. In addition, sites could be selected that include grassland and green area uses.

The measurements that should be conducted following site reclamation (soil replacement) and annually thereafter include:

- particle size distribution (baseline only)
- organic carbon content
- bulk density
- water-holding capacity

Microbial biomass carbon would be a useful measurement to evaluate the rate of recovery of the microbial population in the replaced topsoil following salvage and storage.

The parameters listed above should also be assessed at corresponding control sites as well.

9.2 VEGETATION PERFORMANCE

Vegetation monitoring will allow for an assessment of the productivity of cultivated crops and the re-establishment of grasslands and forest cover. The measurements that should be undertaken include:

- Monitoring yield potential of cereal grains, oil seed, and pulse crops for consecutive years to assess changes in productivity with time
- Monitoring biomass of forage crops with time
- Monitoring natural recovery rates at grassland and green area sites
- Monitoring natural invasion or ingress of native species at sites initially seeded at varying seed application rates to establish cover. This includes all herbaceous and woody species with emphasis on shrub recovery
- Monitoring survival and growth rates of tree seedlings planted on sites where no initial cover seeding has occurred compared to planting into an initial cover
- Conducting rangeland health assessments at selected sites

9.3 EFFECTIVENESS OF PRE-CONSTRUCTION SITE ASSESSMENTS

Many of the individuals interviewed in the criteria revision process commented on the usefulness of pre-construction assessments relative to site construction. These assessments provide the opportunity to improve soil salvage practices and ultimately have a positive impact on soil quality/capability and vegetation performance.

Monitoring activities could involve a comparison of replaced soil quality/capability and vegetation performance on sites where a pre-construction site assessment was done compared to a site where one was not done. This should be done particularly in areas of Luvisolic and Solonetzic soils where soil management requires more attention.

The parameters to be measured would include:

- soil depth replacement
- texture (clay content)
- organic matter status
- aggregate properties
- vegetation performance

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APPENDIX 1: STAKEHOLDER CONTRIBUTORS

Numerous individuals knowledgeable in oil and gas reclamation issues were contacted during the preparation of this report. Their views on reclamation issues and reclamation criteria were solicited.

Consultants
Sixteen Alberta-based consultants were contacted.

Oil and Gas Industry
Four Alberta-based environmental coordinators were contacted.

Landowners
Eight Alberta landowners were contacted.

Regulatory Staff
Fifteen members of Alberta Environment or Alberta Sustainable Resource Development were contacted.

One regulator each from British Columbia and Saskatchewan were also contacted.